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Economic analysis on the 400K DWT VLOC

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ECONOMIC ANALYSIS ON THE 400K DWT VLOC

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Declaration

I certify that all the material in this research paper that is not my own work has been identified, and that no materials are included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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Abstracts

Title of Research paper: **ECONOMIC ANALYSIS ON THE 400K DWT VLOC**

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There are emerging more and more demands of VLOC transportation for the route of Brazil to Far East. The dissertation is an economic analysis of 400K dwt VLOC. Iron ore price changes and transportation costs are closely linked to globalization of world economy. Economics of different sizes VLOC are compared at a designated route of Tubarao/Brazil to Qingdao/China; shallow water affection is taken in consideration of the increasing capacity of VLOC. SOG is adjusted to the right time of high tide to pass the shallow water in the passage as per Master's order. A common mathematical model is established through the detailed analysis of VLOC to prove the economics of 400K dwt ore carriers. Using advanced system evaluation method to compare with key indicators of the same vessel type of ore carriers but different DWT to analyze the reasons of the advantages and disadvantages. Find the root cause of disadvantages and point out where can be corrected to build an economic VLOC. Through this economic analysis, the optimization of the economic performance and comprehensive technical are proposed for the VLOC design and suggestion of widely adopting 400K dwt VLOC for iron ore transportation.

KEYWORDS: VLOC, Brazil/Far East Trade, Economic Analysis, Mathematical Modeling, Techno-economic

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List of Abbreviations

AIS	Automatic Identification System
BW	Bergesen Worldwide
BSFC	Brake Specific Fuel Consumption
BDI	Baltic Dry Index
CDSC	Coefficient of Deadweight, Speed - Continuous Service Rating
C/E	Chief Engineer
CHC	Coefficient of Holds Capacity
CIF	Cost Insurance and Freight
CMES	China Merchants Energy Shipping
CSR	Continuous Service Rating
CVRD	Companhia Vale do Rio Doce
COF	Contract of Freightment
D/C	Deck Cadet
DNV	Det Norske Veritas
DRC	Daily Running Costs
DSME	Daewoo Shipbuilding & Marine Engineering
DWT	Dead Weight Tonnage
EEDI	Energy Efficiency Design Index
EWRIP	Extra War Risk Insurance Premium
FC	Fuel Consumption
FEM	Finite Element Modeling
FWE	Finished With Engine
GC	Great Circle
GHG	Green-House Gas

HFO	Heavy Fuel Oil
H&M	Hull & Machinery
HSFO	High Sulphur Fuel Oil
LOA	Length over All
Lpp	Length between Perpendicular
LSD	Lashing, Securing and Dunnaging
LSFO	Low Sulphur Fuel Oil
IPCC	Intergovernmental Panel on Climate Change
KG	Kilogram
KTS	Knots
MCR	Maximum Continuous Rate
MDO	Marine Diesel Oil
M/E	Main Engine
M/V	Motor Vessel
N MILES	Nautical Miles
OAP	Over Aged Premium
OPEX	Operating Cost
PDM	Ponta da Madeira
RDW	Ratio of DeadWeight
RGT	Ratio of Gross Tonnage
RFD	Ratio of Fuel consumption daily and Deadweight
RL	Rhumb Line
ROI	Return on Investment
RPM	Revolutions per Minute
SFOC	Specific Fuel Oil Consumption
SMS	Safety Management System
SOG	Speed over Ground

T/C	Time-charter
T&P	Temporary and Permanent notices
UKC	Under Keel Clearance
ULOC	Ultra-Large Ore Carrier
VLOC	Very Large Ore Carrier
VTIS	Vessel Traffic Information Service
VTS	Vessel Traffic System

Chapter 1 Introduction

1.1 Background

China is leading the global large amount commodity consumption growth even if its economy has slowed down for years. Iron ore supply is still increasing according to statistics of the expansion project for global iron ore. Iron ore production capacity investment is still increasing by scale of one hundred million tons until 2017, and most of the new increment from mining giant's expansion with lower cost compared to small and medium-sized competitors. (China Commercial Wise, 2016, March 22) However, any commodity fell into bear market will not be absolutely smooth and without resistance. For iron ore, since fallen below $100/ton, various versions of the cut production was spread in the market, but still failed to prevent the iron ore price trend. The economic cycle tells us that any goods are not long presented a unilateral market. In 2005, the average price of Chinese imports of iron ore to the coast was $66.75/ton; the data was $71.15/ton in February, 2015. (Iron Ore China Net, 2016) Iron ore price within a whisker away from a decade ago, 10 years may be the beginning of a new cycle from the perspective of Juglar Cycle. In that way, whether iron ore price hit the bottom in the year of 2015? From the supply point of view, low-cost iron ore will enter the market is a foregone conclusion in the future. New demand to absorb iron ore expansion or high-cost iron ore production is replaced still depends on the future global demand of steel.

Supply and demand is to determine the long-term trend in commodity prices of the underlying factors, iron ore freight rates has no exception. Due to the special nature of the iron ore trade negotiation mode, once the iron ore benchmark price is reached, maximum uncertainty of steelmakers will be cost of iron ore transportation. As in recent years shipping market volatility, especially iron ore price fluctuations relatively large, so how to choose the right time to transport the iron ore or how to charter vessel of VLOC are very important issue to be faced by iron ore importers. Shipping costs are an important part of the cost of steel, higher shipping costs will push up the steel production costs and the company will be at a disadvantage of the competition in the industry.

New building price of VLOC is relatively higher than other small size bulk carriers. CVRD has built 400K dwt iron ore carriers to reduce unit transportation cost. Iron ore was mainly carried by Capesize vessels below 300K dwt from Brazil to Far East before 2008. New building price and second hand vessels price of VLOC are vulnerable to market fluctuations as this kind of vessel carries single kind of cargo, iron ore only.

China and other Asian countries, such as South Korea, Japan are importing more and more iron ore, so the Asian market is increasing demand of iron ore carriers, which greatly stimulated the development of very large ore carrier. The number of VLOC increased significantly and large-scale development trend is very clear. The outbreak of 2008 financial crisis made iron ore seaborne market obviously changed, market performance is staying at low level now. Face with large-scale trends and the background of global economic recovery, whether shipping companies should invest to build bigger size of VLOC to adapt the changes of market demand has become the core study of shipping enterprises investment. This is the background of this topic and the practical significance.

1.2 Objective

Firstly, the objective of this dissertation is to *investigate* the effects of current giant VLOC transportation efficiency and energy conservation. Secondly, it is to *determine* the economics of VLOC subject to the several mentioned correlative factors. Thirdly, it is to *prove* assumption through an application to VLOC Brazil/Far East trade route and Techno-economic analysis.

1.3 Methodology

Iron ore price and transportation costs are closely linked to the world economy. There have emerged large demands of VLOC transportation from Brazil to Far East. The main purpose of this dissertation is to establish a model to analyze the factors which influence economics of 400K dwt VLOC, provide a reference of decision-making to related shipping company, but also offer suggestions of VLOC chartering to iron ore trading company and Techno-economic analyzed. To achieve above mentioned purpose, firstly, the dissertation will analyze different factors that affect the transportation efficiency of iron ore carrier through mathematical model. Secondly, accumulate data of different size of ore carriers which include traditional Capesize and different size of VLOC (175K, 300K and 400K) to compare the economics of profit margin. In order to make the approach of this paper more clearly, we will use a case study to find whether the size of VLOC is the bigger the better and have a calculation to prove it. Thirdly, based on the mentioned calculation, we will conclude which size of VLOC is better for the route of

Brazil/China and Techno-economic analyzed.

1.4 Outlines of the dissertation

Chapter 2, literature review, overview related researches, studies and reports on the economics of VLOC. A couple of studies state clearly effects of economics of 400K dwt VLOC, vessel structure, ship handling and Quantitative Methods on Economics of the vessel. **Chapter 3, economic factors of VLOC,** in this chapter, bunker consumption, various costs, VLOC transportation benefits and external factors are analyzed to support the transportation efficiency of 400K dwt VLOC. **Chapter 4, Economics Analysis of VLOC,** algebra model is used to determine the speed of the vessel and profit margin then an application to different capacity of VLOC (175K, 300K and 400K) is used to assess the profit margin of same route of Tubarao/Brazil to Qingdao/China to prove the economics of 400K dwt VLOC. **Chapter 5, conclusions**, Findings and limitations of this dissertation are summarized and practical recommends for relative shipping operators.

This study could be a reference to VLOC shareholders to make reasonable arrangements and potentially improve the company's competitiveness as a result of strategic planning has a direct applicability.

Chapter 2 Literature Review

2.1 Introduction

There are plenty of researches on the vessel structure of VLOC by scholars and ship builders to build a larger vessel to carry more cargo, but seldom to discuss sailing safety promoting positive role for the economics of VLOC. It was the first time of VLOC 400,000 DWT sea trial built by Rongsheng Heavy Industries Group Holdings Limited for CVRD on November 10, 2011. VLOC M/V "Vale Malaysia" (built in 2012) called Chinese port of Lianyungang on April 15, 2013. (Xzbu, 2014) These are historic moments of 400,000 DWT VLOC was put into the Chinese iron ore market and had a strong impact on the international shipping industry as this type of vessel will reduce unit transportation cost of the route Brazil/China.

According to Clarkson statistics, there are more than 30 VLOC of 400,000 DWT (four of them 388,000 DWT) in custom-made and some of them have been delivered to ship owners. Among the major owner in addition to CVRD has ordered 19 vessels, there are Berge Bulk, Oman shipping, STX Pan ocean shipping company and other well-known bulk cargo transport companies.(Cosbulk, 2011) Most of 400,000 DWT VLOC are used to transport iron ore from Brazil to China route. Based on my working experience on VLOC as seafarer, there are about four voyages per year (including waiting time in anchorage, loading and discharging time at the berth) to carry 1.6 million iron ore from Tubarao/Brazil to Qingdao/China by a single vessel totally. Thus, 400,000 DWT VLOC is marking the international iron ore trade and transportation entering a new phase, may have a significant impact on the international dry bulk shipping market. For the sake of bulk fleet operation, unit transportation cost reduction is always the key point of operation. And furthermore, Green-House Gas (GHG) emissions could be substantially lessened through expansion of vessel capacity which may relief environmental debt of bulk carrier.

In this chapter, effectiveness of VLOC Transportation will be reviewed firstly. Secondly, the Vessel Structure and Operation Issues will be observed. Lastly, different quantitative methods on Economics of VLOC will be studied.

2.2 Effectiveness of VLOC Transportation

Iron ore transportation by 400K dwt VLOC is deemed to be an economic way by shippers, charterers and ship owners. There are three main advantages of VLOC are lower unit transportation cost, reduction in bunker consumption and GHG emissions to lessen environment impact.

2.2.1 Effect on transportation cost

(1) More and more huge capacity VLOC built

I read BW shipping company's publication of World Horizon[1] when I was working on board Capesize vessel of M/V SG Enterprise that is one of bulk carrier managed

[1] World Horizon is a BW Group's quarterly publication.

by BW Fleet as D/C in 2006. I found the company was planning to build 4 VLOC of 388,000 DWT for the first time. Before that, iron ore was mainly transported by Capesize vessels below 300,000 DWT from Brazil to China, larger than bulk carrier M/V Berge Stahl[2] is considered uneconomic or technical level is difficult to achieve. M/V Vale Brasil, the first 400K iron ore carrier was successfully delivered to Brazil's giant mining company Vale by DSME in March of 2011. DSME was planning to build a series of seven sister vessels, each of them is 362 meters LOA and 65 meters of breadth and with a huge loading capacity of 400,000 DWT. (Cosbulk, 2011) CMES is holding signing ceremony to build 10 VLOC of 400,000 DWT in Shenzhen on March 23, 2016. In accordance with the requirements of the agreement, the total construction price of 10 VLOC is $850 million, the first ship delivery time is about the first half of 2018 and the last ship of delivery is no later than the end of 2019. (China International Ship's net, 2016)

(2) Solution of increasing loading efficiency

M/V Vale Brazil was applied EL-2 to ensure loading efficiency; DNV's efficient loading notation allows operators more flexible loading sequences to ensure more efficient loading and safety for this kind of specialized 400K dwt iron ore carrier. Each cargo hold is allowed to be filled by one pass duration of loading operation in port at very high loading rate and without compromising vessel's strength and fatigue life of the vessel. VLOCs with EL-2 have an official documented very high loading rate and significantly reduce loading time in port, which is a must procedure for Vale vessels. (DSME Delivering Vale Brazil, 2011) "The loading patterns and envisaged operating should be designed at the initial stage of ship building, vessel structural strength and adequate hull girders are the fundamental prerequisites for safety of

[2] The biggest bulk carrier was Berge Stahl which was built in 1986, 364767 DWT.

accommodating one-pour loading operation in the future. Moreover, proper dimension of main ballast lines and capacity of all ballast pumps, including designed separated stripping system are very important to the loading port operation. These key factors have been taken into account by ship yard at the early vessel design phase to maximize benefits." says Mr Lee Hwa Lyong, Project Director of DNV's Approval Centre in South Korea who was supervising the vessel of Vale Brazil society approval process. (DSME Delivering Vale Brazil, 2011)

(3) Lower unit transportation cost than traditional Capesize vessel

Various costs were saved around 25% by comparison of 400,000 DWT VLOC and traditional main transportation standard size of bulk carrier (175,000 MT) at the same conditions of bunker cost and exchange rate. 25% of various costs take up around 16% of total costs. (Yang, 2014, February) For instance, the freight rate is 20.75 dollars per ton in Nov. 2013, ship operators can save up to 3.32 dollars per ton if they transport iron ore by 400,000 dwt VLOC instead of traditional Capesize vessel by expected cost minimization model.

2.2.2 Effect on Bunker Cost

(1) Relationship between fuel consumption and vessel speed

First and foremost, Corbett, J.J., Wang, H., and Winebrake, J. (2009) propose bunker fuel consumption (FC) of existing merchant vessels are directly linking to power of Main Engine (M/E P). (Corbett, Wang, Winebrake, 2009) Generally speaking, bunkers consumption is mainly determined by installed M/E power, load factors of vessel main/auxiliary engines as specified speed. Therefore, based on these factors, Kontovas C., and Psaraftis, H. (2010) gave the following formula:

$$FC\ (ton/day) = P(kW) \times BSFC\ (gr/kWh) \times 10^{-6}\ (ton/gr) \times 24 (hr/day) \tag{2.1}$$

Since the variance of “Brake specific fuel consumption” (BSFC) is a low constant, authors concluded with a couple of surveys of different engine manufacturers that BSFC can be a constant. Therefore, another variable in formula (2.1) is power of M/E which is closely related to the bunker fuel consumption. (Kontovas &, Psaraftis 2010) While there is another kind of expression of BSFC is specific fuel oil consumption (SFOC), Cariou, P. (2011) who calculated daily bunker fuel consumption of M/E through load factors as vessels are built at designed sailing speed, which is about 80% of the MCR (engine maximum continuous rate). Found the BSFC&SFOC are set about 190gr/kWh in most researches. (Cariou, 2011)

Secondly, there is a cubic relationship adopted to express relationship between vessel speed and bunker fuel consumption. (Faber, 2010, p.7) Dong Z. (2008) mentioned the resulting of an exponent of 3.33 and R^2=0.99 through the method of regression model in his thesis (Dong, 2009) However, the cubic law of vessel speed and fuel consumption is not always right. Base on the Barrass, C.B. (2004) research, an exponent of 4 or higher will be adopted while vessel speed higher than 20 kts. (Barrass, 2004)

(2) Considerable bunker cost in shipping

Firstly, bunker cost is a main part of shipping costs. Stopford, M. (1997) has mentioned that bunker cost takes up about 47% cost of the voyage total costs which can be applied to all types of shipping. (Stopford, 1997, p. 160) On the other hand, there is a relatively large fluctuation in bunker prices. According to different databases, for instance, Bunker world and Clarkson Research Lab, bunker fuel prices went up sharply since 2007, and peaked at $679/ton in Rotterdam in July of 2008. Therefore, it is a big challenge to control bunker fuel consumption for cutting bunker costs. Notteboom T., and Vernimmen, B. (2009) proposed three major methods to cope with the fluctuation of bunker fuel price (a) actions regarding to the size of the vessel and economic speed of the whole fleet; (b) actions in ship’s design and (c) using cheaper grades of bunker fuel. (Notteboom & Vernimmen, 2009) Bunker cost is recognized as the voyage costs by traditional way of vessel costs allocation.

(3) Economic speed for saving bunker

The Baltic Exchange (2013) suggested panellists that slow steaming of bulk carrier they should assume speed at 12kts in vessel laden voyage/13kts in ballast condition, Capesize vessels normally consume 44 tonnes per day. However, users of Baltic information should know that Baltic Exchange expects panellists reporting their T/C routes to consider the prevailing market conditions, consumption of Baltic defined vessels in the prevailing circumstance for bunker costs and freight rates, and the likely steaming speed as well. (MarineLink, 2013)

Secondly, using iron ore carriers as the target vessel, by analyzing the whole vessel life cycle operating cost of the general running costs of fuel and different enrichment of nuclear fuel composition. The results show that: when the fuel oil prices above $450 per ton, nuclear fuel enrichment is 4.45% of the ore carrier nuclear fuel compared with the conventional ore carriers, nuclear-powered vessel has a better fuel economy of the entire life cycle; meanwhile, when nuclear fuel enrichment is 16.5%, the nuclear-powered vessels have a better fuel economy. (Zhou, & Hong, 2012)

2.2.3 Effect on Emission Reduction

The 67th session of IMO Maritime Environment Protection Committee (MEPC) was held in London to discuss various issues in relation to air pollution and energy efficiency from 13 to 17 October 2014. MEPC 65th discussed a proposal to enhance energy efficiency of the international shipping from United States through a phased approach (MEPC 65/04/19) and another document MEPC 65/04/30 that supported the development of operational measures and technical to increase energy efficiency of the vessels. Low-carbon economy designed to save fossil energy that is based on carbon fuels civilized industrial society to an ecological community which based solar civilized economic operation transition mode. (Xu,X.G., 2016)

(1) Measurement of emission

In General, the "emission factor" is to measure GHG emission. By definition, we know that emission factor is regarding to weight (kg) of CO2 emission from each ton of fuel consumed. Logically, we can multiply the amount (ton) of fuel burned; weight of CO2 can be calculated. The factor of 3.17 was proved from empirical test in some papers. However, it is separated into MDO (Marine Diesel Oil) and HFO (Heavy Fuel Oil). Because of different nature, both of them have different factors. Kontovas and Psaraftis (2010) suggested that 3.17 was not fuel-dependant. IPCC 2006 (Intergovernmental Panel on Climate Change) showed the factor 3.19 used to MDO and 3.13 for HFO. We know that bunkers consumption is mainly talking about HFO as this is fuel for M/E. According to the average of carbon molecular weight of different fuels, 3.02 was used for HSFO (High Sulphur Fuel Oil) and 3.08 was recommended to LSFO (Low Sulphur Fuel Oil) (International Maritime

Organization, 2008) Laboratories testing used for the determination of emission calculation factors shall be accredited according to EN ISO/IEC 17025. Intertek has been working with some major refineries in Europe for the CO2 emissions control by means of testing services and verification of measurement equipments. Calculation of emissions shall be performed by this formula: Emission factor ×Activity data ×Oxidation factor (Intertek)

(2) GHG emissions

The world's largest ore carriers 40K DWT is a low carbon economy, low energy consumption, low pollution and low-emission. The vessel not only reduces the unit cost of transportation, but also ton-miles fuel consumption and CO2 emissions lower than the same type of vessel; its Energy Efficiency Design Index (EEDI)[3] is less than 2, two years ahead to reach international Maritime organization predetermined emission reduction requirements. (Xu,X.G., 2012) The new method is to add two main parts: firstly, CO2 emissions reduction even at low speed by combination of a turbocharger which can be operated at high efficiency while at low rpm with an electronically-controlled main engine. Secondly, propulsion is assisted by the waste heat energy recovery. By combination of above two, CO2 emission is cut by30%. (Seatrade, 2010)

Cariou (2011) introduced the following formula to make an estimation of CO2 emission changes where ME stands for bunker fuel consumption by vessel main engine SFOC, load factor is around 90% and T stands for total time in port and at sea separately and have a hypothesis of bunker consumption in port is 5% of which vessel at sea because of FWE in port. (Cariou, 2011)

[3] EEDI is based on the ratio of CO2 emissions and the ability to characterize cargo vessel energy efficiency

$$ME_K = SFOC_K \times LF_K \times P \tag{2.2}$$

$$\Delta CO_2 = 3.17 \times \sum_{k=1}^{n} (ME_{k,sea} \times T_{k,sea} + ME_{k,port} \times T_{k,port}) \tag{2.3}$$

To sum up, we have reviewed some research achievements based on the effectiveness of transportation from three aspects in this part: transportation cost, bunker cost and emissions reduction. Outcomes are very impressive to us; probably that is why bulk fleets have a big crush on reducing unit transportation cost. In next sector, vessel structure and operation issues will be studied.

2.3 Vessel Structure and Handling

Since ore is very heavy cargo with small volume and the hull of ore carrier is easily damaged. Therefore, ore carrier has to be built with robust construction, cargo holds bottom bulkhead beveled to prevent iron ore horizontal movement, and to enhance the strength of the hull. Density of ore is large with small stowage factor, so it takes up relative small cargo hold space, which causes ship's center of gravity is too low, and GM value is too high to result in rolling relative heavily during the voyage.

2.3.1 Vessel Structure

As early as in 1980s, two Great Lakes dry bulk carriers were presented to calculate the hull deflection in a way of machinery spaces by Movses in 1982. Modeling and analysis of the finite element methods were discussed and calculated the results compared to measure results. Shaft bearing influence coefficients were calculated with hull flexibility and then an application of proposed alternation to existing vessel was analyzed. (Movses, 1982)

Valemax ore carriers, the LOA 362m, breadth 65m, design draught of 23m (Summer draft load line), draft design speed 14.8kn, continuation of the journey 25,000 n miles. It is single propeller and single rudder with special straight bulbous bow, seven cargo holds with hydraulic sliding hatch covers, and a helicopter landing on the main deck. Cargo holds are in the form of a typical arrangement of ore carriers, in the premise of cargo loading requirement, to determine the appropriate cargo holds volume by optimizing the ballast condition to obtain the best speed optimal arrangement of ballast tanks and ballast state. Integrated bridge system and unmanned engine room automation is to ensure excellent handling performance. VALEMAX type is the maximum scale ore carrier which is able to meet existing Tubrao/PDM ports of Brazil and some Chinese ports draught limit. (CNSS, 2014)

There is a great difference in structure between very large ore carriers and traditional bulker, a typical cross-sectional view with distinctive features, and super large hull makes the structural performance requirements much attention. Due to the special nature of the hull and the large-scale structure, it is beyond the scope of existing norms; therefore, it requires the use of the whole vessel finite element method to calculate the structural strength of the hull. Study on very large ore carriers, discusses the modeling methods of VLOCs finite element model of the structure and quality model, wave load calculation methods and internal cargo load calculation methods, as well as solve the whole vessel inertial load dynamic equilibrium balance processing technology, to form a set of very large ore carriers structural strength direct calculation process. (Luo, Q.M., 2010) Because of ultra large scale and the special vessel structure, normal methods like cargo hold FEM and beam theory in rules cannot be directly applied to analyze the vessel hull strength of this type of ultra large ore carriers. Based on the research of ULOC analysis by FEM, different methods of setting up whole structural finite element model and the mass model, describing internal load distribution, calculating wave loads and technique of achieving the inertia balance for dynamic balance of the whole vessel loads are developed. Taking a 450K DWT ULOC as an example, whole vessel hull analysis is done with results of the hull relative deformation, and stress in the different load cases. (Luo, Q.M., Xue, H.X. & Tang, W.Y., 2010)

First-principle-based calculation method was developed to assess transverse compression strength of the cross-deck structures in very large ore carrier. The cross-deck concept and associated structures are introduced where the cross-deck and other relative structures attached making contribution to the resist transverse compressive load. The effects of hatches arrangement and cargo holds, cargo inertia loads, cargo profile, wave head pressures and still water have been taken into consideration. Calculation procedure was developed and is written to make straight-forward assessment, and links general particulars of the vessel, its hold dimensions and hatches are directly to the safety factors. (Cheng, F., & Zhu，L., 2014) Vessel strength studies provided important information regarding possible hazards on the very large ore carriers.

2.3.2 Ship Handling

Murdoch said that ship handling is an art rather than a science. However, ship officer who knows a little knowledge of science will be helpful at his art. Knowledge of science will enable the ship mate easy identification of vessel's manoeuvring characteristics and a quick evaluation of his skills needed for vessel control. (Murdoch, et al.，2004)

Firstly, review very large ore carriers handling characteristics was introduced in different situations at sea, such as effect on current and route planning (passage plan) to optimize vessel's economy etc. Secondly, focus on vessel maneuvering in port (mooring, unmooring and areas presented to the wind in Appendix Ⅱ, Bulk carrier practice) and cargo operations to propose ore carrier berthing procedures and precautions.

2.3.2.1 Operations at sea

(1) Propeller Slip

Propeller Slip is considered as the difference between the actual ship's speed and the speed of the main engine which is always expressed as a percentage (%) and determined from the formula:

$$\text{PropellerSlip}\,\% = \frac{\text{Engine speed} - \text{speed of vessel}}{\text{Engine speed}} \times 100 \qquad (2.4)$$

The result of slip is the smaller the better. (House, D.J., 2007) However, it is more sluggish to response to the helm when propeller slip is smaller.

(2) Ocean current and tide

Ocean current flows for a very long distance and creates global conveyor belt, and it plays a leading role to determine climate of many regions on the earth. The movement of ocean water is one of most important factors of accumulated discrepancy between actual position and dead reckoned of the vessel. Motion of water is called current; the direction toward and speed are named set and drift. Modern merchant vessel speed has lessened impact of current during the voyage, and electronic navigation helps continuous adjustment the course of the vessel, it is less works to do an estimation of current drift and set while setting steered course by ship mates. A useful knowledge of global ocean current helps captain to reduce transit times and current model is recognized as an integral part of routing system. (Bowditch, N., 2002) Some ore carriers transit South Atlantic Ocean, via Cape of Good Hope and then pass through Indian Ocean to Malacca Strait from Brazil to China. Vessel encounters Ocean Current and should take advantage of current to speed up the vessel for a shorter transit time of voyage.

(3) Weather Routing

Bowditch (2002) introduced vessel weather routing is to form an optimum track of ocean voyage which is based on sea conditions, forecasts of weather during the voyage and vessel individual characteristics for particular transit. Second officer prepare the passage plan based on accumulated information and instruction of nautical publications, master should approve it before sailing. Within specified limits of sea and weather conditions, the term of optimum is to maximum safety and comfort for crew, and minimum of time underway, minimum bunker fuel consumption, or desired combination of these mentioned factors. The vessel routing agency plays as an advisory service, and attempts to reduce or avoid the effects of adverse sea or unsettle weather conditions by issuing route recommendation prior to sailing of the serviced vessel. Bowditch also mentioned advantage of weather routing accrues when: (1) weather is an important factor to determine routes for the vessel; (2) the waters in the passage are navigationally unrestricted, so the routes can be chosen (RL or GC); and (3) the passages should be relatively long, 1500 n miles or more as it will lose its function if it is a short voyage. (Bowditch, N., 2002)

2.3.2.2 Operations in Port

(1) Draught and trim

Mr. House (2007) mentioned that VLOC is the vessel which has deeper draft in laden condition and more sluggish will be ship's response to the helm. However, while ore carrier is in ballast condition which is shallow draught and lead to her superstructure more exposed, and would be much more influenced by the wind. The trim of ore carrier will influence the size of her turning circle considerably. Vessels are usually trimmed by the stern for better handling purpose but which should be noted that when she was trimmed by the head the turning circle would be distinctly reduced. (House, D.J., 2007) We know that it is important for ore carrier to adjust trimming at the last stage of loading and keep her even keel or a little bit trimmed by the stern for better economic speed and maximize the cargo loaded. (Shear Forces and Bending Moment in Appendix Ⅲ, Bulk carrier practice)

(2) Stability

Captain Middleton (2002) mentioned that seafarers must be responsible for the strength and the stability of their vessels. These two aspects are essential disciplines to ensure safety of vessel at sea. The dynamics characteristics of vessel is determined by its stability and loading. (Middleton, R.B., 2002) Stability is changing during loading and discharging, Chief Mate is in charge of the plan of loading and discharging sequence ensuring the vessel conforms to GM value requirement. **Safety is expensive, no safety is more expensive.** We cannot talk anything about economy without safety.

(3) Ballast water control

Captain Isbester (1993) mentioned a lot about ballast water management in his book of Bulk Carrier Practice, sea water is used aboard bulk carrier as ballast to improve vessel's draft, air draft, trim, list and stability. Cargo is unloaded and ballast is loaded to maintain vessel at an acceptable trim and draft. Ore carrier will carry nothing in ballast condition from discharging port to next loading port. Ballast water is discharged by pumps installed on board vessel before or whilst cargo loading takes place. Iron ore is located in the areas like Brazil, Australia that requires little return cargo from Far East. VLOC spend 40-50 per cent of their time in ballast whilst smaller bulkers carry wider variety of cargoes and on average in ballast condition 30-40 per cent of the time. (Buxton, I. L. and Logan, J.A., 1986) Ballast water protects the vessel from heavy weather damages, avoids infringing regulations and for propulsion is very important element in the efficiency of ship's operations. (Isbester, J., 1993)

(4) Golden Rules of Berthing

There are actions should always be taken by master before and during vessel is in progress of berthing. Passage plan should be made from berth to berth even there is not specified berth available at times. Making sure that pilot understands the vessel's manoeuvring characteristics. Take tug assistance into consideration, where current and wind or ship's handling characteristics that create difficult berthing conditions. To avoid high forward vessel speed when using bow thruster, when sailing in a narrow channel, when UKC is small, when close to other vessels or when working with tugs. Remember that the vessel's pivot point is forward of amidships while steaming ahead. At low ship’s speed, wind and current have a greater effect on vessel maneuverability and high-sided will experience pronounced effects from leeway. Never ring 'finished with engines' (FWE) until all mooring lines have been made fast. Always expect the unexpected to occur and anticipate well ahead. (Murdoch, et al., 2004)

2.4 Quantitative Methods on Economics of VLOC

Many researches and papers glued potential expenses and benefits together observing the economics of 400K dwt VLOC for the sake of bulk shipping. A couple of researches dig deep insight the benefits/costs of the strategy seeking lower unit transportation cost could be applied. In the section, bunkers reserve, resistance and propulsion of the vessel and relations between fuel consumption, displacement and vessel speed will be reviewed.

2.4.1 Bunker reserve

(1) The total amount (Q) of bunker reserve calculation

$$Q \geqslant (1 + 15\%)\, q \tag{2.5}$$

where q is expected total bunker consumption of the voyage, including M/E and auxiliary engine (generators and auxiliary boilers) bunker consumption to refueling harbor or port of destination, but not including remaining oil cannot suck out from the fuel tanks; partially accounts for 2-5% of the total amount of the fuel cannot burnt when using poor quality fuel. **Under normal conditions, a vessel fuel reserve is not less than the amount of bunker for two days consumption.**[4] (Bunker consumption and speed, 2015)

2.4.2 Relations between fuel consumption, displacement and vessel speed

1. When the vessel displacement is constant, one hour fuel (F) consumption is in direct proportion to V^3 (speed).

$$F \propto V^3 \tag{2.6}$$

2. When the vessel speed is constant, the relationship between fuel (F) consumption and the vessel displacement (D) is:

$$F \propto D^{2/3} \tag{2.7}$$

3. Relationship between total fuel consumption (q) and daily consumption (F):

$$q = F \times (\text{number of days of navigation}^{5}) \tag{2.8}$$

In the charter party, there are provisions of speed and fuel which requires the Beaufort wind force 4 and waves DOGLAS level 3 sailing speed, and both cases of

4 Different companies have their own operation procedure of bunker reserve estimation, not necessarily 2 days.

5 The number of days of the voyage should take into account the impact of the monsoon.

fuel consumption for ballast condition and laden condition.[6] (Bunker consumption and speed, 2015)

2.4.3 Resistance and propulsion of the vessel

There are many methods to calculate the total resistance of the vessel. Following is the formula of LAP method.

$$R = 55.25 \times C_t \times V_s \times (3.4\nabla^{\frac{1}{3}} + 0.5L_d) \times \nabla^{\frac{1}{3}} \times [1 + (\frac{B}{T} - 2.4) \times 0.05] \qquad (2.9)$$

The accelerated speed is zero when the vessel sails at constant speed, which means propulsion is equal to resistance. From formula 2.9, found that the resistance is increased in direct proportion to $\nabla^{\frac{1}{3}}$, therefore, the bigger size of VLOC will be the more efficient of transportation.

2.5 Summary

In this chapter, we have reviewed relevant researches from different aspects, namely, effectiveness of VLOC transportation, vessel structure and handling issues and Quantitative Methods on Economics of VLOC. From an objective perspective, the strategy of 400K dwt VLOC built is obvious to lower the unit transportation cost. Huge costs saving both in bunker and environment protection attract ship owners to built bigger size of ore carriers. (Cosbulk, 2011) Nevertheless, some of ship owners' interest has largely sacrificed since traditional size of Capesize vessel carries

6 Laden condition refers to the case of the summer load line.

cargo less than half of 400K dwt VLOC. In term of economics of VLOC, most of scholars agreed with the 400K dwt VLOC should be built for the iron ore transportation. (Yang, 2014)

Generally, it has a very huge system to take all related factors into consideration for the economics. This literature review provides us not only several quantitative analyses on the strategy, but also more qualitative review are confirmed. Therefore, in next chapter, economic factors of VLOC will be presented detailed analysis.

Chapter 3 Economic Factors of VLOC

3.1 Introduction

It is widely accepted by most researches, larger capacity of VLOC is effectively to reduce unit transportation cost and cope with high bunker cost, but bunker cost is not the only decisive criteria for VLOC building. In this chapter, we will introduce economic factors of VLOC and algebra method used to assess the economics of 400k dwt VLOC.

3.2 Bunker cost

3.2.1 Bunker Fuel Price Evolution

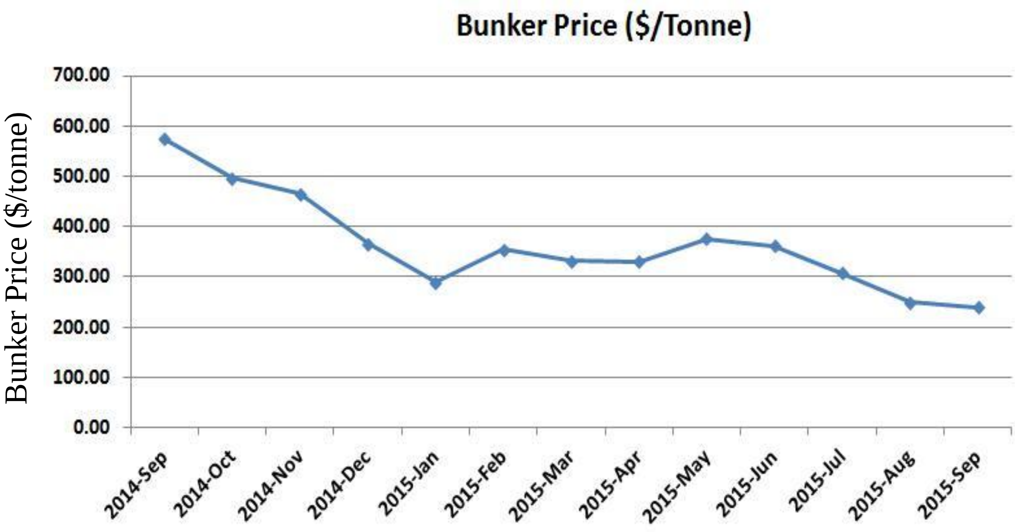


Figure 1- Monthly Bunker Price at Port of Singapore Evolution 2015-09 ($/tonne)

Source: Own presentation based on the accumulated data from Clarksons Shipping Intelligence Network (2015)

Figure 1 depicts the fluctuation of bunker fuel[7] price at Port of Singapore where is recommended as the one of most convenient bunkering ports for the route of Brazil to Far East. The Bunker fuel price of 380 CST went down all the way and finally below the price of $300/tonne in the early of 2015. And then with a slowly upwards, the fuel price is between $300 to $400 dollars per tonne. Moreover, the second half of the year 2015, the bunker price went down again closed to $200/tonne.

Down-trend and volatility were two main characteristics of bunker fuel price during oil crisis in 2015. The former has a positive effect on reducing total costs which help carriers endure through the difficult period of bear bulk market. In the last couple of years, bunker fuel price was increasing in conformity with the price of crude oil. The latter is risky to shipping as bunker fuel cost is a large part of total costs. Many shipping companies hedged the bunker fuel price fluctuation for sustainable development. It is obvious that shipping companies cannot influence the bunker fuel price and crude oil price that is controlled by the oil giant. Therefore, shipping companies respond to the super high bunker fuel price is to effectively save the bunker fuel.

3.2.2 Bunker Consumption

3.2.2.1 Speed and bunker consumption

[7] 380 CST grade – CST means the unit centistokes and it relates to the kinematic viscosity of the residual fuel

In chapter two, we have mentioned there has a cubic law between speed and bunkers consumption variation that has been proved by many researches. The daily bunkers used by vessel depend on her speed and hull resistance.

$$FC_{SS} = FC_d \times \left(\frac{V_{ss}}{V_d} \right)^3 \qquad (3.1)$$

Where:

FC_{SS} = bunker fuel consumption at slow steaming (tons/day)

FC_d = designed bunker fuel consumption (tons/day)

V_{ss} = vessel speed at slow steaming (knts x 24 = n miles/day)

V_d = vessel designed speed

The cubic law is applicable to most of merchant vessel. In order to prove the effectiveness of vessel speed reduction on bunker fuel consumption, it is essential to accumulate very large ore carrier data of designed speed and bunker consumption. With the help of C/E Lin D.F. who works for Berge Bulk, we extracted vessel particulars of VLOC with 5 same grade vessels observations and get the mean design speed and bunker consumption. The age of the vessels are limited younger than 15 years as the age of the vessels differing bunker consumption by 20% or more.

Our estimations are based on cubic law to different vessels of varying speed which is from designed vessel speed to actual speed (Minimum effect of wind and current) and the corresponding fuel consumptions.

Figure 2 illustrates the relationship between the vessel speed and fuel consumption.

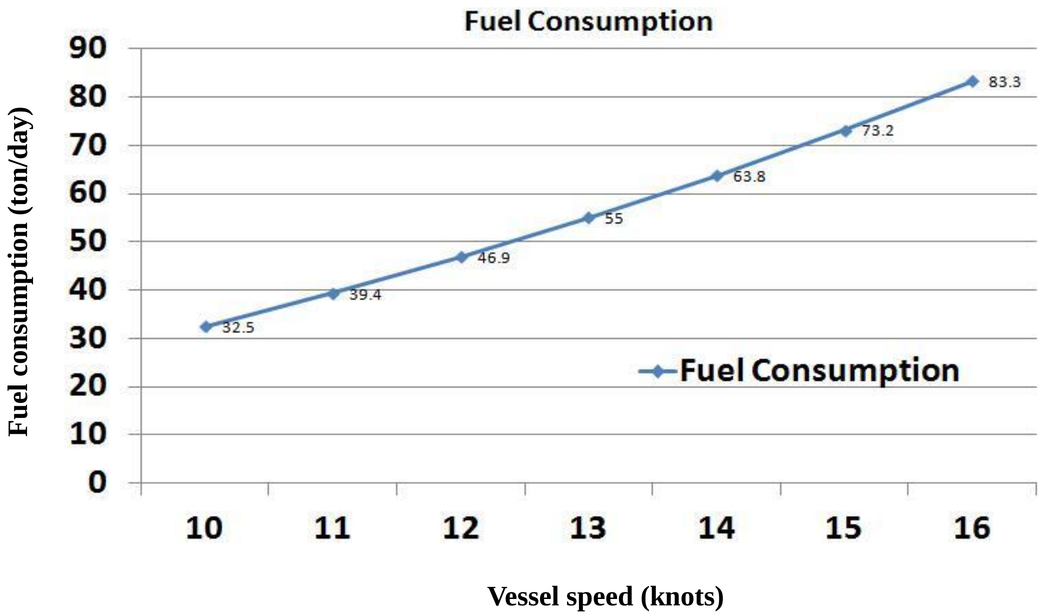


Figure 2 - Relationship between Vessel Speed and Fuel Consumption
Source: Own presentation based on data provided by Chief Engineer Lin

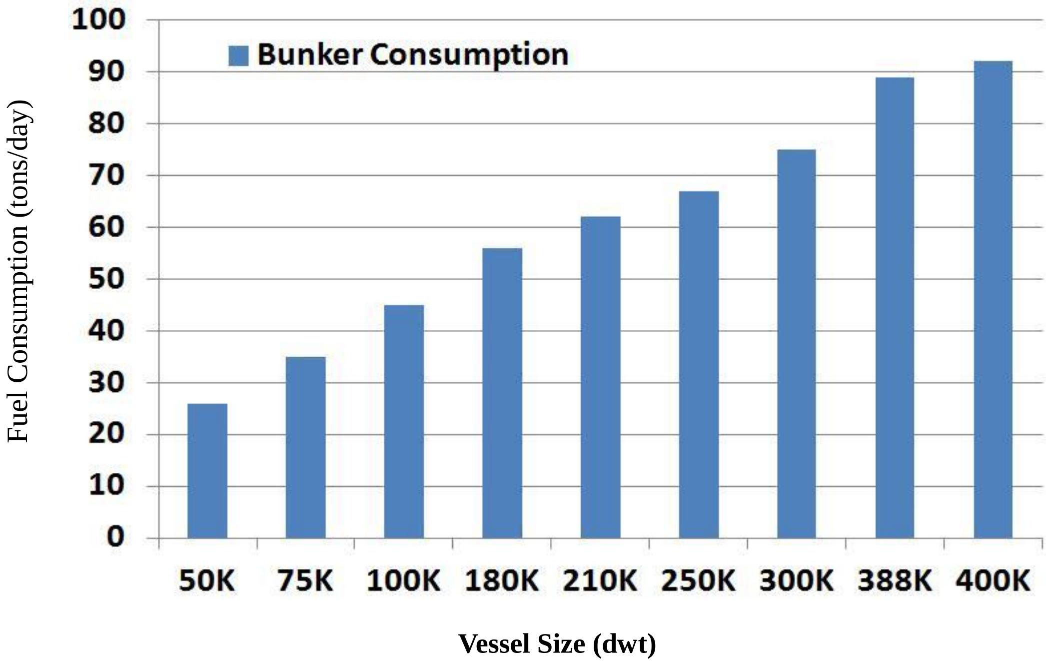
We found that is corresponding to Cubic Law and the effective of vessel speed reduction. However, the fuel consumption is getting steep with the vessel speed increased. Fuel consumption is depending on vessel age, hull condition and machinery as well. The figure also indicates that dropping in vessel speed result in a drastic reduction in bunker fuel consumption. For instance, two knots (from 15 to 13 knots) reduction in vessel speed will save up to 18.3 tons fuel per day for a 300K dwt ore carrier. If the bunker price is around $600/ton, which 18.2 tons of bunker saving translates into daily bunker cost saving up to $10,920. But the cost effectiveness is not always in the same proportion. It will diminish if the vessel sails further slower, less than 10 knots, bunker cost saving is not very obvious for very low speed. Compared to container vessel, ore carriers are steaming lower speed and lower bunker consumption. It seems that has not big gap for ore carrier’s speed reduction for bunker cost saving since the different vessel characteristics. However, as long as bunker fuel price goes up, lower vessel speed will bring more bunkers costs saving. Table 1 shows the results of Fuel Consumption Estimation.

Table 1 - Results of Fuel Consumption Estimation[8]

Size of Vessel	300K dwt
Designed Speed	14.0 knots
Fuel Consumption	63.8 Tons
Speed Variation (knots)	**Fuel Consumption (tons/day)**
10	32.5
11	39.4
12	46.9
13	55
14	63.8
15	73.2
16	83.3

Source: Own calculation based on data from C/E Lin

3.2.2.2 Vessel size and bunker consumption



[8] Estimation based on equation 3.1

Figure 3 - Relationship between Vessel Size and Fuel Consumption
Source: Own presentation based on data from C/E Lin

Figure 3 depicts the relationships between vessel size and daily bunker fuel consumption. According to the observations and estimations, bunker fuel consumption is getting flatter with growth of the ore carrier size. Apparently, very large ore carriers came into operation for a few years only, particularly, the 400k dwt vessel, this is largely due to diesel engine and vessel design technology improved. Apart from vessel building technique, the vessel cost effectiveness is largely relying on vessel speed variation. Therefore, CVRD built larger and larger ore carriers for iron ore transportation.

3.3 Various Costs

Cost estimation is vital for charterers, operators and shipowners. It is also important for the traders who are not charterers of the vessels. This is because an accurate cost estimating makes a very different result between a large loss and a healthy profit of the vessel. Blum (2016) mentioned there are six "Golden Rules" for voyage estimating: 1. Select the same Estimate Form 2. Keep the Estimate Form neat 3. Check and double-check your calculations. 4. Use your imagination for the case 5. File the finished Estimate Form for reference. 6. Perform a voyage estimate result for the fixed vessel. (Blum, 2016) In this section, we will introduce operating costs, voyage costs and cash flow to verify the economics of VLOC.

3.3.1 Operating Costs (OPEX)

Operating costs are also known as vessel's DRC (Daily Running Costs). These are the costs that the shipowners have to pay in order that their vessels are both legally and financially afloat in accordance with domestic and international regulations.

Operating costs include insurance premium H&M (Hull & Machinery) and OAP (Over Aged Premium) that usually takes up 20% of the fixed costs. These costs also include financing of the vessel and paying for daily maintenance, repairs, spare parts, dry docking and special surveys. Operating costs also include victuals, fresh water and cost of hiring crew (medical, repatriating and official documentary needs). Cost of looking after all crew members and paying for them take up approximately about 45% of most vessels' operating costs. (Blum, 2016) In comparison to other costs, these costs are more or less constant and can be predicted.

Crew manning has become one of the most critical in today's shipping industry. It is difficult to find qualified officers and increasing wage for experience officers are reported by many shipping companies.

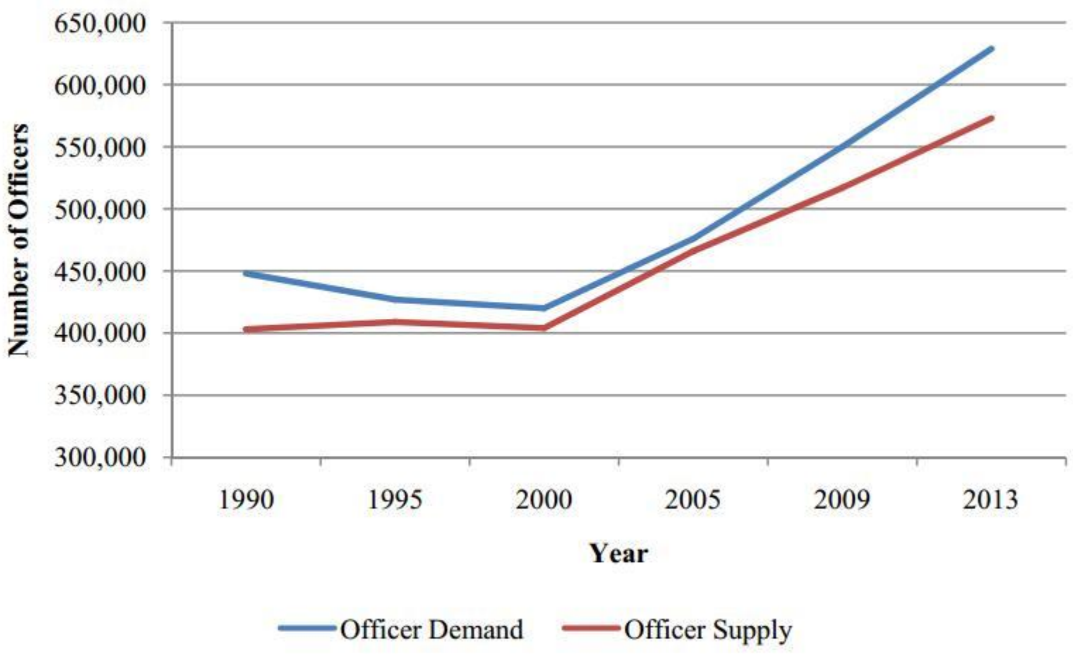


Figure 4 - Seafarers Demand and Supply Imbalance
Source: ISF/BIMCO (1990-95), Drewry/ PAL (2009-13)

Although new technologies are emerging, it is still impossible to operate a vessel without a qualified captain. Figure 4 vividly depicts the gap between demand and supply of officers in shipping industry during last two decades. Demand of officers surpassed supply in the whole period while it is getting worse in the future. It is almost the same crew members for the vessel 40K dwt and 400K dwt. That is the cost of hiring crew is almost same for these quite different size vessels and this reflects the economics of VLOC. However, more and more officers are reluctant to work on board vessel will push higher officer's wage which will finally lift up OPEX.

3.3.2 Voyage Cost

Voyage costs change from voyage to voyage. The cost of bunkers is the biggest part of voyage costs. The voyage distance and time of port stay need to be calculated as accurately as possible in order that the total quantity of bunkers (diesel oil and fuel oil) can be estimated exactly. Bunker fuel cost form the largest proportion of the voyage cost, and is subject to the biggest fluctuation.

Voyage costs also include canal charges and many other different port disbursements. Also, there are additional expenses for specific handling certain types of cargo ashore or on board, which is known as "LSD" (lashing, securing and dunnaging). Ore carrier loads cargo in the cargo holds only and covered by hatch covers, there is not cost of LSD for deck cargo for this type of vessel. There may also include EWRIP (Extra War Risk Insurance Premium) if the vessel goes to an area of hostility or a war zone for specific voyage. (Blum, 2016) Do not miss that shipbrokers' commission and charterers' address commission are also included in voyage cost.

Every voyage has four stages that include: Firstly, ballast voyage from last known place of previous voyage; secondly, loading operation in loading port(s); thirdly, laden voyage to carry the cargo to discharging port(s); fourthly, unloading operation in discharging port(s). Ore carriers have almost half of the time in ballast condition at sea since return cargo of the routes is imbalanced.

3.3.3 Cash Flow

Capital costs are related to debt issue which is through capital repayment. Vessels are used as shipowners' investments which will generate capital gains or loss and a stream of cash flows. (Kavussanos, 2016) Table 2 is the cash flow of T/C (Time-charter) and spot (voyage) markets for shipowner, which is different from COF (contract of freightment).

Table 2 - Cash Flow in T/C and Spot Markets for Shipowner

T/C Market	**Spot (voyage) Market**
T/C Hire	Voyage Hire
Less: operating costs	Less: operating costs
N/A	Less: voyage costs
= Operating Earnings	= Operating Earnings
Less: Capital costs	Less: Capital costs
Plus: profits (loss) from selling and buying vessel	Plus: profits (loss) from selling and buying vessel

= Capital Gain/Loss	= Capital Gain/Loss

Source: Own presentation based on Kavussanos' handout, 2015

3.4 VLOC Transportation

More and more 400k dwt ore carriers are joining the routes of Brazil/Far east. There are plenty of advantages of VLOC transportation that affect unit transportation cost, value chain, shipping routes and social benefits.

3.4.1 Unit transportation cost

In order to study the unit transportation cost, we take route Tubarao/Brazil to Qingdao/China as an example and the vessel types are 400K dwt VLOC and traditional Capesize vessel (17.5K). The total distance to be covered is around 12,000 n miles via Cape of Good Hope and Malacca Strait. (400K VLOC passes Sunda Strait) 95% of full load (summer load line), average speed is 14.3 knts, assume four voyages annually (four ballast voyages and four laden voyages). Bunker cost in ballast voyage is two thirds of laden voyages. (Yang, 2014, February)

Table 3 - Unit transportation of 400k dwt VLOC and 175k dwt Capesize vessel

Vessel types	Annual Total costs (m $)	Annual Transportation (T)	Unit Transportation Cost ($/T)
400k DWT	1977.8	158.5	12.5
175k DWT	1158.4	69.4	16.7

Source: Own presentation base on data from Yang Chunzhi, (2014).

Table 3 shows the advantage of unit transportation cost of 400k dwt VLOC in the same condition of interest rate and bunkers price. It can save up to 25% of transportation cost, which takes up 16% of total costs. For instance, the freight rate is 47 dollars/ton in 2009, the transportation cost can be saved up to 7.5 dollars per ton by 400k dwt ore carrier.

3.4.2 Industry chain

Transportation cost is fluctuant and it is an uncertainty risk not only for steel companies, but also the whole industry chain members who cannot be avoided. Chinese steel companies have a great demand of iron ore, but retail orders and the purchase mode make the COF signing rate is still low, it is difficult to achieve a balanced amount of monthly imports. Japan and South Korea's manufacturers are binding to large-scale and long-term package transportation contracts to reduce the transportation costs. High transportation costs lift up raw material costs, prompting steel companies to avoid high fluctuation of shipping costs and the prices of iron ore production by increasing inventory. Since investments in warehousing facilities has increased expense which is leading to rising costs and resulting in a vicious cycle.

For iron ore suppliers, the longer distance transportation, the higher transportation cost, the actual iron ore CIF is pushed higher as well. Shipping market volatility makes the competitiveness of high-quality iron ore is further weakened, thus affecting the production and operation of iron ore suppliers. It has higher risk of shipping enterprise investment. Demand and supply of transportation capacity has never been able to achieve a balance, making it difficult to achieve the profit-maximizing investment efficiency, ships and other necessary production facilities have also been greatly affected. By using 400k dwt ore carriers change the business model and the vicious cycle of high freight costs, it also can improve the relationship of the whole industry and meet the needs of the common interests of many enterprises.

3.4.3 Shipping Routes and Social Benefits

The total distance to be covered from Tubarao/Brazil to Qingdao/China is around 12000 n miles, which is the total sailing time is about 35 days by Capesize vessel. However, the distance from Port Headland/Australia to Qingdao is about 4200 n miles, 11 days for one-way voyage.

Table 4 - Iron ore transportation distance

Loading port	**Discharging port**	**Distance (n miles)**	**Transportation time (days)**
Port Headland	Qingdao	4,200	11
Tubarao	Qingdao	12,000	35

Source: Own presentation

Some of figures in Table 4 show that the distance from Tubarao to Qingdao is around 3 times of distance Port Headland to same discharging port, which leads to 3 times of transportation cost. Iron ore transportation cost from Brazil takes up 9-50% of CIF while it is only 6-25% of Australia iron ore export. (Yang, 2014, February) Brazilian route transportation is more sensitive to freight rate fluctuation than Australia route. For instance, there is a gap of transportation cost of 5-7 dollars for these two routes when the freight rate is at low level. However, the gap will be 50-70 dollars when the freight rate at high level. That is the main reason that 400k dwt iron ore carrier was built by CVRD to improve their competitiveness.

400k dwt ore carrier is an environment friendly and energy conservation vessel which can reduce sulfur and carbon compound 9% and 34% compared to 300k dwt and 175k dwt ore carriers. (Yang, 2014, February) It is estimated that 50 to 100 vessels of 400k dwt ore carrier will join the route and will drive the ship building industry, ship-repair and vessel service industry forward. Meanwhile, larger berths are constructed, which will relieve port congestion and anchorage waiting time to help cost reduction of the whole supply chain.

3.5 External Factors

All VTS requirements, relevant T&P notices, port/coastal states reporting requirements, danger areas closed to route, parallel indexing information and other significant danger issues and tidal predictions where appropriate should be marked on the charts. At no time will safety of the ship be jeopardised by commercial pressure to conduct in an unsafe manner or contrary to the requirements of the company's SMS (safety management system). (Paul,2011) There shall be no conflicts between the safety of the crew，the vessel and the environment, or the specific commercial consideration when a passage plan is made.

3.5.1 Maritime Geography Channel Depth

(1) Port Information

There are often channel depth changed or/and specific requirements for operations in ports, passing specific locations, off port limits etc. Information regarding port facilities and requirements can be found in the Fairplay Ports Guide. All staffs are reminded to use publications with care since the publishers do not guarantee entirely accurate information contained nor do they accept any responsibility for omissions, errors etc. Masters of the vessel are encouraged to advise the publishers with updated information for revision in future editions.

Depth of navigation channel is changing due to port conditions, tidal stream and wreck etc. Port authority shall maintain the channel depth for the big draft vessel to avoid aground in port; deeper channel maintenance requires higher dredging cost.

Min. Channel Depth = Load Draught + Min. UKC[9] (3.1)

(2) Malacca Strait

There are two kinds of waypoint selection for route of Brazil to China via Cape of Good Hope and south of Madagascar. Sometimes, we passed through Sunda Strait for vessel 400K dwt; most of the time, will choose the route of Malacca strait for bunkering in Singapore in ballast voyage. Table 5 is a part of Voyage Log Abstract I made when I was working on board vessel of BW fleet in 2011. We chose the route via Malacca Strait as there has lower bunker price in Singapore during the voyage, but it is suitable for 400K dwt VLOC in ballast condition only. It is essential to work with local VTIS to promulgate the safety information as ore carriers are restricted to her draft and maneuvering difficulty. Keep clear of the dangers Batu Berhanti / iwo Buffalo Rock and review safety information and communicate with other vessels in good time to ensure every vessel knows what is happening. AIS can also be used for information on other vessels.

[9] The minimum allowable UKC has different requirements in port or at sea.

Table 5 - Part of Voyage Log Abstract

FORM 5.108a

FILE:

VESSEL: **SG PROSPERITY** **085L**

FROM: **PDM** Date: 16-Aug-11 FAOP: 0930LT **TO:** **SG** Date: 18-Sep-11 EOP: 1900LT

Date	Steam	Distance			Average			Weather (Dir x Scale)			FO Consumption (Tons)						DO Cons.		Water	
	Hours	Obs	Eng	Log	Speed	rpm	Slip	Wind	Sea	Swell	M/E	Aux.	Blr/IGG	T/C	Ball.	Total	Aux.		Made	Used
2011-9-3	24.0	320	364	302	13.33	74.0	16.93	5*6	5*5	5*5	63.40	2.50	0.0	0.0	0.0	65.90	0.0		19	13
2011-9-4	24.0	312	362	308	13.00	73.6	14.82	5*4	5*6	5*6	63.20	2.50	0.0	0.0	0.0	65.70	0.0		18	12
2011-9-5	24.0	324	364	309	13.50	74.1	15.12	5*5	5*5	5*5	63.40	2.50	0.0	0.0	0.0	65.90	0.0		18	9
2011-9-6	23.0	299	349	295	13.00	74.2	15.56	4*4	5*5	5*5	60.50	2.30	0.0	0.0	0.0	62.80	0.0		17	12
2011-9-7	24.0	305	362	307	12.71	73.7	15.21	5*4	5*5	5*5	63.20	2.50	0.0	0.0	0.0	65.70	0.0		18	11
2011-9-8	23.0	287	348	288	12.48	74.0	17.34	3*5	5*5	5*5	60.30	2.40	0.0	0.0	0.0	62.70	0.0		17	8
2011-9-9	24.0	299	364	299	12.46	74.0	17.76	3*4	5*4	5*4	63.30	2.50	0.0	0.0	0.0	65.80	0.0		17	14
2011-9-10	24.0	296	363	295	12.33	73.9	18.75	2*5	5*4	5*4	63.40	2.50	0.0	0.0	0.0	65.90	0.0		18	12
2011-9-11	23.0	276	345	278	12.00	73.3	19.44	3*5	5*4	5*4	60.60	2.40	0.0	0.0	0.0	63.00	0.0		17	15
2011-9-12	24.0	294	360	295	12.25	73.2	17.97	2*5	5*4	5*4	63.50	2.50	0.0	0.0	0.0	66.00	0.0		17	3
2011-9-13	24.0	299	360	304	12.46	73.3	15.58	2*5	5*4	5*4	63.60	2.60	0.0	0.0	0.0	66.20	0.2		17	14
2011-9-14	23.0	281	346	295	12.22	73.4	14.63	3*4	5*4	5*4	60.70	2.40	0.0	0.0	0.0	63.10	0.0		16	17
2011-9-15	24.0	311	362	311	12.96	73.7	14.11	3*4	5*4	5*4	63.50	2.50	0.0	0.0	0.0	66.00	0.0		17	15
2011-9-16	24.0	309	362	309	12.88	73.7	14.66	3*3	4*3	4*3	63.40	2.50	0.0	0.0	0.0	65.90	0.0		17	14
2011-9-17	23.0	296	348	296	12.87	74.0	15.04	1*3	7*2	7*2	60.70	2.60	0.0	0.0	0.0	63.30	0.0		16	19
2011-9-18	22.0	280	330	276	12.73	73.2	16.27	1*3	3*2	3*2	58.30	2.30	0.0	0.0	0.0	60.60	0.0		0	13
TOTAL	781.5	9663.0	11788.8	9710.0	12.36	73.7	17.63				2063.30	82.20	0.0	0.0	0.0	2145.50	0.2	0.0	563.2	443.1

Remarks :

Source: Own presentation, calculated in Sep. 2011

3.5.2 Under Keel Clearance (UKC)

The requirement for minimum UKC shall be taken into consideration while carrying out commercial voyage plan and determining the total quantity of cargo to be loaded. When the vessel is underway, the minimum allowable UKC should include an allowance of squat; 1. In ports, it is not less than 10% of the deepest static draught. 2. In fairways, approaching channels or any other similar waters are not less than 15% of the deepest static draught. 3. It is not less than 20% of the deepest static draught during ocean passages. (Paul, 2011)

Paul mentioned there are many factors shall be taken into consideration when calculating the controlling depth for the passage.

a) Recent weather patterns may affect the water level

b) Tide / Sea state / currents (known / forecast)

c) Charted depths at the anchorage area and possible reduction of depths over pipelines

d) Charted depth within 0.5 miles to each side of planned route (for vessel through transits)

e) The nature of the sea bottom (e.g. sand wave phenomena)

f) Water density of the waters (salt and fresh water difference)

g) Handling characteristics and the vessel's size, and increase in vessel draught due to heel or other motions of the vessel

h) The accuracy of tidal predictions for the waters and Hydrographic data

i) The reliability of vessel's draught calculations and observations, including estimates of sagging or hogging of the vessel

3.5.2.1 Tide effect

Chinamax vessels are very large ore carrier which cannot be wider than 65 m (213 ft), longer than 362m LOA (1,180 ft), and draft cannot be more than 24 m (79 ft), and the deadweight tonnage of the vessels is about 380,000–400,000 DWT. Vessel's maximum measurements are defined the Chinamax standard, which allowing Chinese discharging ports to determine if they can accommodate vessels or not in this class. As the ship's name suggests, these vessels are often used to carry cargo to China and several trade routes, such as iron ore route of Brazil to China. However, it is not the bigger the better, all factors should take into consideration before executing a new voyage, such as tide effect.

Tidal heights are important for navigation; for instance, many ports have some shallow "bar" in the channel or at the entrance or in the port limits which prevents vessels from entering at low tide with significant draft. Tidal flow is also essential to navigation, sometimes, significant plotting error in position made by ship mates. Velocities and timings of tidal flow can be referred in tidal stream atlas or tide charts.

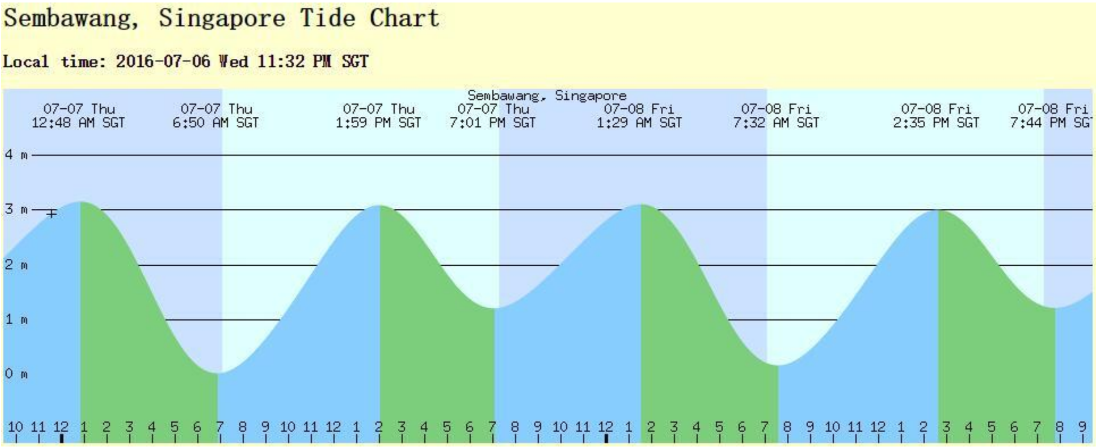


Figure 5 - Singapore Tide Chart on 06-Jul-2016
Source: Mobilegeographics

Nautical chart displays the depth at specific positions with "soundings" and bathymetric contour lines to depict the shape of the submerged surface. All water depths are relative to a same "chart datum", which is typically the lowest water level of astronomical tide (although different datums are used as well).

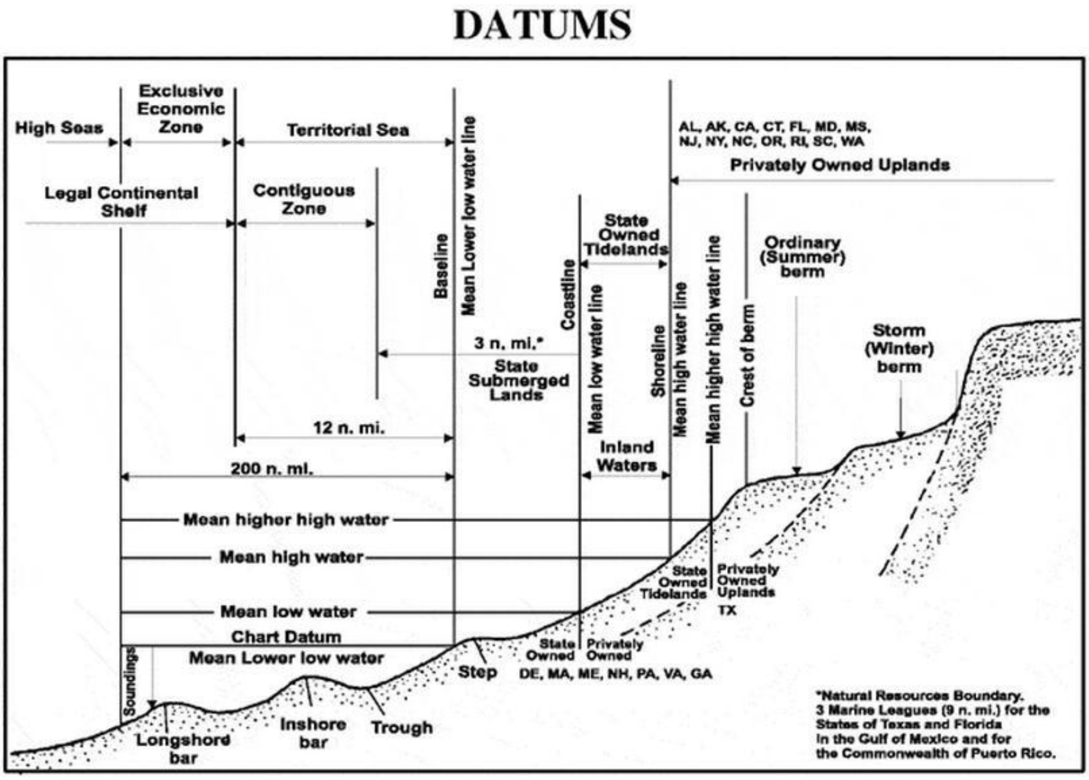


Figure 6 - Datums
Source: Wikipedia

3.5.2.2 Squat and Interaction

(1) Squat

Squat is basically the sum of vessel hull sinkage and trimming effect, which means the reduction of UKC due to vessel's moving forward motion through the water. For the vessel squat calculations, channel width (>500m) is considered to be open waters. The channel width is <500m but >200m, the squat calculation can be determined by (Figure 7) interpolation. The amount of squat calculation can be twice of open waters when the vessel is in confined waters where the width and depth of channel are reduced. Figure 7 tells us that the simplest method to reduce vessel squat is to reduce its speed.

Squat (cm) = Block Coefficient (C_b[10]) x Speed^2 (3.2)

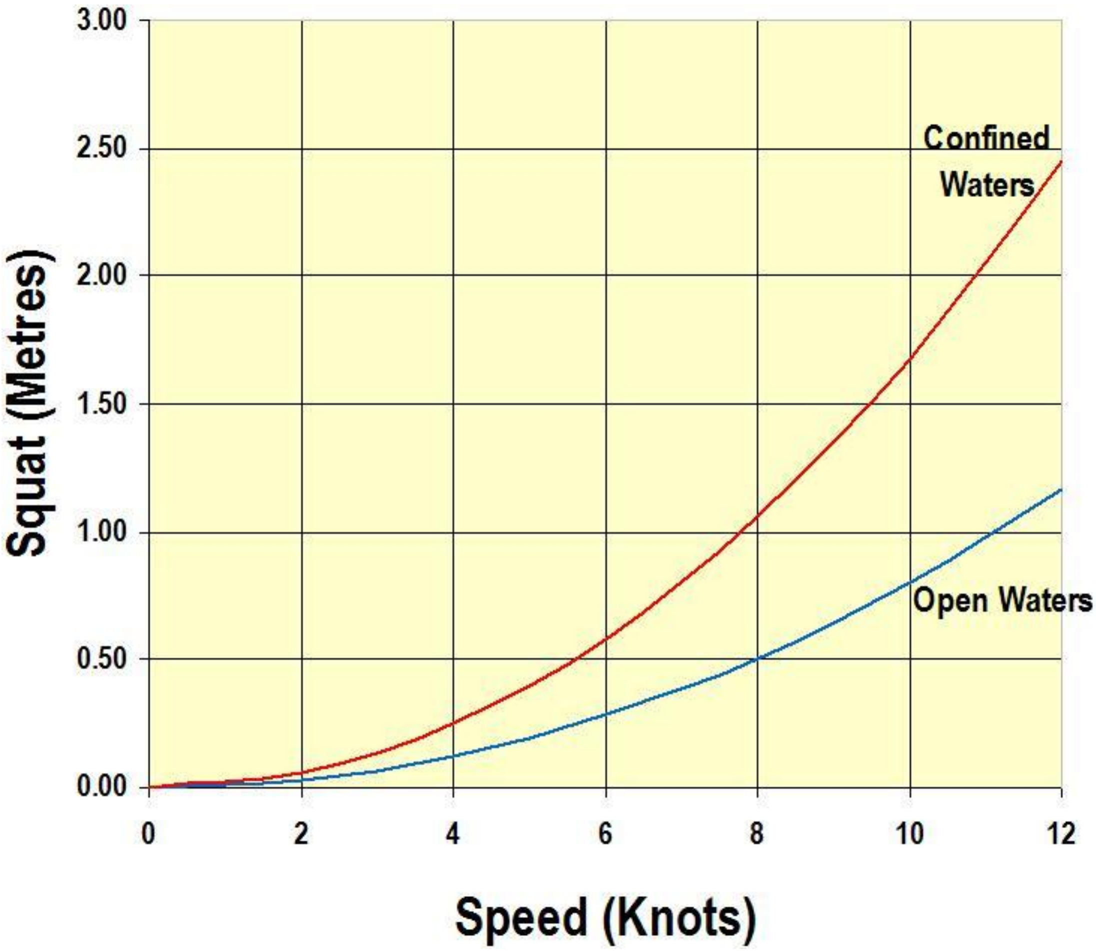


Figure 7 - Squat estimation
Source: (Paul/BWFOP,2011)

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[10] a measure of the shape of the vessel underwater hull $C_b = \frac{\nabla}{L \times B \times T}$

(2) Interaction

Interaction is the effect of one ship may have on another while they passes close by or the vessel is manoeuvring close to breakwater / canal side / river bank etc. This phenomenon can be a lot of forms in confined waters, when transiting a canal, lying at alongside river berth, etc. as may be appropriate. 1. Overtaking 2. Bank effect 3. Head on passing 4. Moored alongside 5. Tugs alongside / close by

3.6 Summary

We list out four major economic factors that relate to the economics of VLOC in this chapter. Firstly, we assume that bunker costs have not fluctuation and nothing influence from oil market, it is the only way for ore carriers to cut considerable bunker fuel costs is to maintain economic speed to control over daily fuel consumption. We also calculate the bunker fuel consumption of same vessel at different speed and different vessels in terms of loading capacity based on cubic law. Secondly, various costs that include operating costs, voyage cost and capital cost are the important costs for shipowners or investors to have a well decision making whether the vessels should be assigned to transport cargo or not. We know that manning is the biggest proportion of operating costs, which is predicted increase in the future as lack of officer supply in shipping market. Thirdly, VLOC transportation benefits, industry chain is changing consequently as more and more 400k dwt ore carriers joining the world bulk fleet. Also, the unit transportation cost will be much lower and it will improve Brazilian ore exporter international competitiveness, meanwhile, traditional capesize vessel operators will be impacted by the ore carrier market. Revolution always creates new opportunity and benefits to society, port congestion will be relieved and shipping route affected. Fourthly, External factors, base on passage planning, ore carrier is restricted by channel depth at loading port and discharging port and Malacca Strait of the route Brazil to Far East. Hence, tide effect, squat, sagging, hogging (Appendix I, Bulk carrier practice) and vessel interaction should be taken into consideration to ensure the minimum UKC requirement in whole passage.

We will have a comparison/profit margin study in next chapter by setting some parameter constant to observe how the economics of 400k dwt VLOC is affected.

Chapter 4 Economics Analysis of VLOC

4.1 Introduction

In this chapter, we will establish algebra of energy conservation by reducing vessel speed and the economic speed analysis and profit margin, and then application of different size (175k dwt, 300K dwt and 400k dwt of VLOC) to the algebra. Furthermore, techno-economic analysis of modern 400K dwt ore carrier will be also established to compare the advantage of this type of vessel.

4.2 Algebra of Maximum Profit Margin and its corresponding speed

(1) Relationship between bunker fuel consumption and vessel speed

M/E of the vessel transforms bunker fuel directly into mechanical energy, and then transfer to propeller to push vessel forward to overcome hull resistance at a certain vessel speed. (Wu, 1994)

M/E total power requirement:

$$P = M_{\mathrm{n}} P_o = \frac{RV}{102\eta_p \eta_s} \tag{4.1}$$

$$R = \frac{1}{2} C\rho SV^2 \tag{4.2}$$

Where: P = total power of M/E

M_n = the number of Engine

P_o = the output power of each M/E (KW)

R = the hull resistance (kg)

V = the vessel speed without wind and currency affection (m/s)

η_p = propulsive efficiency of propeller

η_s = shaft transmission efficiency

C = vessel resistance coefficient

ρ = water density（$kg.s^2 / m^2$）

S = the surface submerged

From formula 4.1, higher vessel speed and higher hull resistance require bigger developed power of M/E; therefore, the vessel will consume more fuel. For merchant vessel such as VLOC, hull resistance includes frictional resistance and form resistance. We know that ship's hull resistance (R) is in direct proportion to V^2 (vessel speed).

From formula 4.1 and 4.2, we can conclude the following formulas

$$P_o = \frac{C\rho SV^3}{204 M_n \eta_p \eta_s} \text{ (KW)} \tag{4.3}$$

Fuel consumption each hour:

$$F_{\mathrm{h}} = M_n P_o \mathrm{B_e} = \frac{\mathrm{B_e} C \rho S}{204 \eta_p \eta_s} V^3 \text{(Kg/hour)} \tag{4.4}$$

Where: $\mathrm{B_e}$ = effective rate of Bunker fuel consumption

Therefore, we can calculate how much money will be spent each hour by multiply the price of fuel oil. In the chapter 2, we have mentioned that fuel (F) consumption is in direct proportion to V^3 (speed). All other values are fixed or have a small change, and using Q instead this part, ($\mathrm{B_e}$ is changed corresponding to P_o, we know that number of running engines are fixed at the period of fixed sea speed.) hence, formula 4.4 can be changed to formula 4.5.

$$F_{\mathrm{h}} = QV^3 \text{ (Kg/hour or dollars/hour)} \tag{4.5}$$

Where: Q is coefficient of vessel function, it relates to propeller function, shape of vessel, draft, depth of water, M/E, quality of bunker fuel and price of bunker fuel etc. the value of Q is determined by experimental measurement at a selected area which is without wind and current affection. In a nutshell, Wu (1994) introduce following equation can be used to express value of Q.

$$Q = 24 \times 10^{-6} \times P_f \times B_e \times P_o / V^3 \quad \text{(Dollars day}^3\text{/km}^3\text{)}$$

Where: P_f = Bunker fuel price (dollars/ ton)

$\mathrm{B_e}$ = effective rate of Bunker fuel consumption (g/Kw.H)

P_o = the output power of each M/E (KW)

V = the vessel speed without wind and currency affection (m/s)

Base on the propeller characteristics, consumed power P_o is in direct proportion to V^3. Therefore, if the vessel speed is reduced, the main engine consumed power will be reduced much more; that is fuel consumption will be reduced as well.

However, Wu (1994) focused on fuel consumption to conclude the value of Q, but ignore the draft of the ore carriers changed dramatically due to their loading condition. For instance, the loading condition of 400k dwt (LPP350m x W65m x D23m) and ballast condition (LPP350m x W65m x D10m), which will change a lot of submerged surface. Ration can be calculated as per Froude formula:

$$S = \nabla^{\frac{2}{3}}(3.432 + 0.305\frac{L_w}{B} + 0.433\frac{B}{d_m} - 0.643C_b)$$

Where: ∇ = Displacement of the vessel

L_w = Length of designed water line (for VLOC, $L_w \approx$ Lpp)

B = Breadth of the vessel

d_m = Draught of the vessel

C_b = Block Coefficient

Therefore, based on formula 4.4 and 4.6, the value of S will be increased by 40% if the vessel in laden condition is taken into consideration. We have introduced that Q is determined by experimental measurement at a selected area which is without wind and current affection and vessel is in her ballast normally. Hence, S' stands for the submerged surface of vessel is in her laden condition, which will affect the value of Q.

$$S' = 1.4S \tag{4.6}$$

Table 6 - Relationship between RPM and power, vessel speed and fuel consumption

RPM (R/Min.)	90	95	100	105
Power (KW)	4340	4780	5660	6620
Vessel speed (miles/h)	12.96	13.50	14.31	15.12
Total fuel consumption (Ton)	41.0	42.8	49.0	54.2

Source: Own presentation based on Wu, M.Y. (1994). Wuhan Traffic Management College Journal, 2, 64-65.

Table 6 tells us the relationship between RPM of M/E and power, vessel speed and fuel oil consumption. When the RPM is reduced from 105 to 90, the power is reduced to 65.56%, the speed is reduced to 85.71% and the fuel consumption is reduced to 75.65%.

In the view of energy conservation, the slower speed will save more bunker fuel; in the point of economy, the slower speed will not get the higher profits as it is not only bunker fuel cost but also vessel depreciation cost, manning cost, insurance premiums, repair charge and spare part etc. which are fixed cost no matter what is the vessel status (underway, alongside or at anchor). Total costs include fixed cost and voyage costs we have mentioned in chapter 3, and total distance can be calculated at a fixed voyage, duration of the voyage will increase if the vessel sails at slower speed. Hence, the fixed cost will increase as well. **We can conclude that the lower vessel speed does not mean the more economic.**

In the point of technical, reducing vessel speed is restricted by many other factors, such as low RPM will cause instability of M/E and increase complexity of M/E management.

Therefore, the lower vessel speed does not mean the better, but should find a balance point (energy conservation speed) not only ensure safe operation of M/E, but also maximum energy conservation.

(2) Economy analysis of vessel speed

Wu (1994) introduced the lowest bunker cost speed[11] and the maximum profits vessel speed. These two kinds of vessel speed are important to decision making for ship owners, charterers and operators.

1. The lowest bunker cost speed

Vessel daily cost can be expressed as followed:

$$C_{\mathrm{d}} = f + QV^3 \quad \text{(Dollar/day)} \tag{4.7}$$

Where: C_{d} = the daily total cost

[11] The speed of lowest bunker fuel cost per n mile

f = the daily fixed cost

QV^3 = bunker cost at ballast condition (without port disbursements)

From formula 4.7, we can calculate cost of each nautical mile.

$$C_n = \frac{C_d}{24(V+U)} = \frac{f+QV^3}{24(V+U)} \quad \text{(Dollar/n mile)} \tag{4.8}$$

Where: U is current velocity.

Counting positively "+" when it is same direction as ship's velocity; and negatively "-" when opposite direction to s ship's velocity.

If we only take bunker cost into consideration, and ignore fixed cost of the vessel. We know how much bunker fuel cost per n mile in formula 4.9.

$$C_n = \frac{QV^3}{24(V+U)} \quad \text{(Dollars/n mile)} \tag{4.9}$$

In order to calculate the vessel speed of the lowest bunker cost, method of derivation can be applied to formula 4.8 and assume the result is zero.

$$\frac{dC_n}{dV} = \frac{24(U+V).3QV^2 - (f+QV^3).24}{[24(V+U)]^2} = 0$$

There are two roots of imaginary root and real root, the real root of formula is

$$V_{opt} = \frac{1}{2}\{[\sqrt{\frac{f}{Q}} + \sqrt{\frac{f}{Q} - U^3}]^{\frac{2}{3}} + [\sqrt{\frac{f}{Q}} - \frac{f}{Q} - U^3]^{\frac{2}{3}} - U\} \quad (4.10)$$

When the vessel sails at the speed of V_{opt}, that is the lowest fuel consumption each mile. Therefore, we call V_{opt} is the lowest bunker cost speed and its corresponding bunker cost is the lowest fuel cost $C_{n/opt}$.

If current velocity is zero, then

$$V_e = \sqrt[3]{\frac{f}{2Q}} \quad (4.11)$$

Affected by the current, at the condition of lowest fuel cost is called the lowest bunker cost speed (V_{opt}). When the current speed is zero, the speed is called the economic speed (V_e).

From formula 4.8 and 4.11, we can conclude that the lowest bunker cost per n mile.

$$C_{n(\min)} = \frac{1}{24}(\frac{f + QV_e^3}{V_e}) = \frac{1}{24}(\frac{f + \frac{1}{2}f}{\sqrt[3]{\frac{f}{2Q}}}) = \frac{1}{16}\sqrt[3]{2Qf^2} \quad (4.12)$$

Formula 4.10 tells us that V_{opt} is a constant when the current velocity is fixed and it will not change due to voyage distance and time of port stay. Bunker fuel cost is the lowest at this speed V_{opt}, hence, the actual vessel speed should be V$\geqslant V_{opt}$.

Formula 4.10 and 4.11 tell us that V_{opt} and V_e are changed corresponding to value of Q and f. Q is affected by bunker price and f is fixed cost of the vessel. Therefore, when the fixed cost is not changed, and the value of Q is lower that means the bunker fuel price is lower, which will get higher value of V_{opt} and V_e and cost of each mile will be reduced. In the same way to draw, when value of Q is higher, which means bunker price going up; slower vessel speed is effective to bunker consumption.

The profit is at low level when vessel is sailing at the lowest bunker cost speed, but it is useful for energy reservation; for the vessels that does not require too much profits can be applicable to, such as passenger vessel. It is quite different to cargo vessel because higher volume of transportation will generate higher profits for ship owners, therefore, the actual speed for cargo vessel should be V$\geqslant V_{opt}$.

2. The maximum profit vessel speed

Ship owners are always pursuing maximum profit from vessel operations. The vessel speed is to determine the total cargo transported and the total costs of vessel. Profit margin is an indicator of the vessel operation. The formula is as followed:

$$\gamma = \frac{I_n - C_t}{T_v} = \frac{I_n - (T_s.C_s + T_p.C_p)}{T_s + T_p}$$

Assume C_p=f and $T_s = \dfrac{D}{V+U}$

$$= \frac{24\frac{I_n}{D}(V+U) - QV^3}{1 + 24\frac{T_p}{D}(V+U)} - f \tag{4.13}$$

Where: I_n = net income of the voyage.

C_t = the total cost of the voyage.

T_v = the time of the voyage. (Day)

T_s = the time at sea. (Day)

T_p = the time in port. (Day)

C_s = the cost at sea per day. (Dollars/day)

C_p = the cost in port per day. (Dollars/day)

D = the total distance of the voyage. (n miles)

From the formula 4.13, we can conclude that the vessel operation profits is determined by revenue of each n mile ($\frac{I_n}{D}$), the ratio between time in port and total distance of the voyage $\frac{T_p}{D}$, fixed cost and vessel speed. **The more cargo carried will generate the more revenue, logistically higher profits, the shorter time in port and the lower cost of fuel consumed will generate more profits as well.** Profit margin will be reduced when fixed cost is raised; hence, reduce fixed cost is a way to increase profit margin. (Wu, 1994)

In order to calculate the maximum profits speed V_r, the method of derivation is applied and assumed the result is zero. $\frac{d\gamma}{dv} = 0$

$$V_r^2 (1 + 24\frac{T_p}{D}U + 16\frac{T_p}{D}V_r) = \frac{8I_n}{QD} \qquad (4.14)$$

Formula 4.14 can be also expressed as followed:

$$1 + 24\frac{T_p}{D}U + 16\frac{T_p}{D}V_r = \frac{8I_n}{QDV_r^2}$$

In order to calculate the speed of maximum profit, from formula 4.13 and 4.14,

$$\gamma_{\max} = 2QV_\gamma^3 + 3UV_\gamma^2 - f \qquad (4.15)$$

The maximum profit margin is corresponding to the vessel speed $\boldsymbol{V_\gamma}$. In practice, the vessel speed should be V≦ V_γ .

If $\gamma_{\max}$ =0, that is the speed of break even. $V_r = V_{opt}$,

$$V_r = \frac{1}{2}\{[\sqrt{\frac{f}{Q}} + \sqrt{\frac{f}{Q} - U^3}]^{\frac{2}{3}} + [\sqrt{\frac{f}{Q}} - V^3 - \sqrt{\frac{f}{Q} - U^3}]^{\frac{2}{3}} - U]\}$$

When the $\gamma_{\max}$ =0, the maximum profits speed is equal to the lowest bunker cost speed. Therefore, shipowners will not choose lowest bunker cost speed as vessel daily actual speed, but it can be used for reference speed of minimum profits.

Hence, the vessel speed should be $V_{opt} \leqq \mathrm{V} \leqq V_{\gamma}$ and close to V_{γ} for making maximum profit.

4.3 Application of Maximum Profit Margin to VLOC (175k & 400k dwt)

Theory of Maximum Profit Margin is analyzed in section 4.2, and formula 4.13 lists out all related factors to profit margin when the vessel is in laden condition. In order to express all factors clearly and highlight the advantage of 400k dwt vessel, we will have an application by comparison of 175k dwt, 300K dwt and 400k dwt ore carriers in the section.

VESSEL 1 (175K dwt), VESSEL 2 (300K dwt) and VESSEL 3 (400K dwt) are used to carry iron ore from Tubarao to Qingdao which via South Atlantic Ocean, Cape of Good Hope, South of Madagascar, India Ocean, Sunda Strait, South China Sea, East of Taiwan, and assume total distance is S=11,500 n miles that is same route applied to three ore carriers. All of them commence their voyages at the same time in order to have a same seasonal current and monsoon impacts and fixed vessel speed of 14 knots, current counting positively 0.7 knot through the voyage. We have mentioned in the formula 4.5, QV^3 is the bunker cost per hour (dollars/hour), we will use real record data in the following examples in table 7, and T_p is the time stay in port (including the time at the anchorage). Fixed costs (f) are different to three vessels. All known conditions used and calculation based on formula 4.13 and results listed in table 7.

Table 7 - Profit Margin Calculation & Comparison

VSL	DWT	LOA(m)	Distance (miles)	Speed (knots)	Current (knots)	Bunker price ($/ton)	Daily bunker (laden) consumed (tonnes)	Daily bunker (ballast) consumed (tonnes)
VESSEL 1	175K	289	11,500	**14**	**+0.7**	300	54	49
VESSEL 2	300K	333	11,500	**14**	**+0.7**	300	74.4	67
VESSEL 3	400K	360	11,500	**14**	**+0.7**	300	96	85

VSL	Daily Bunker cost / laden ($)	Daily Bunker cost / ballast ($)	Time at sea (days)	Total bunker cost/laden ($)	Total bunker cost/ballast ($)	Fixed cost ($)	Total Cargo Transported
VESSEL 1	16200	14700	32.6+32.6	528120	479220	**6500**	173.3K
VESSEL 2	22320	20100	32.6+32.6	727632	655260	**8450**	297K
VESSEL 3	28800	25500	32.6+32.6	938880	831300	**9100**	396K

VSL	Freight rate ($/ton)	Revenue ($)	Time of loading port (days)	Time of DISCH port (days)	Total time in ports (days)	P/M ($) (laden)	P/ M ($) (ballast)	**Profits Margin ($)**
VESSEL 1	13	2252.9k	5	5	10	**39377.8**	**-19245.0**	**20132.8**
VESSEL 2	13	3861K	6	7	13	**72739.9**	**-24997.3**	**47742.6**
VESSEL 3	13	5148K	7	8	15	**97207.5**	**-29575.3**	**67632.2**

Source: Own calculation based on data provided by C/E Lin / BB

For the traditional capesize vessel (**175K dwt**), we can calculate profit margin based on data listed in table 7 when the vessel is at 99% full loaded condition.

$$\gamma_{\text{laden}} = \frac{24\frac{I_n}{D}(V+U) - QV^3}{1+24\frac{T_p}{D}(V+U)} - f = \frac{24\frac{2252900}{11500}(14+0.7) - 16200}{1+24\frac{5}{11500}(14+0.7)} - 6500 = 39377.8$$

$$\gamma_{\text{ballast}} = \frac{24\frac{I_n}{D}(V+U) - QV^3}{1+24\frac{T_p}{D}(V+U)} - f = \frac{24\frac{0}{11500}(14+0.7) - 14700}{1+24\frac{5}{11500}(14+0.7)} - 6500 = -19245.0$$

The route of ore carrier from Brazil to China can be via Malacca strait or Sunda Strait, and there is a little bit distance difference between these two routes. For the vessel more than 260k dwt would like choose the route via Sunda Strait and traditional capesize vessel frequently select the route via Malacca Strait. Because of lack of return cargo, ballast condition takes up almost half of the voyage which means the profit margin is minus. Algebraic sum of profit margin for the vessel is at laden and ballast condition, we can count the vessel is making profit or at a loss.

For the iron ore carrier of **300K dwt**, we can calculate the profit margin as following:

$$\gamma_{\text{laden}} = \frac{24\frac{I_n}{D}(V+U) - QV^3}{1+24\frac{T_p}{D}(V+U)} - f = \frac{24\frac{3861000}{11500}(14+0.7) - 22320}{1+24\frac{6}{11500}(14+0.7)} - 8450 = 72739.9$$

$$\gamma_{\text{ballast}} = \frac{24\frac{I_n}{D}(V+U) - QV^3}{1+24\frac{T_p}{D}(V+U)} - f = \frac{24\frac{0}{11500}(14+0.7) - 20100}{1+24\frac{7}{11500}(14+0.7)} - 8450 = -24997.3$$

For the iron ore carrier of **400K dwt**, we can calculate the profit margin as following:

$$\gamma_{\text{laden}} = \frac{24\frac{I_n}{D}(V+U) - QV^3}{1 + 24\frac{T_p}{D}(V+U)} - f = \frac{24\frac{5148000}{11500}(14+0.7) - 28800}{1 + 24\frac{7}{11500}(14+0.7)} - 9100 = 97207.5$$

$$\gamma_{\text{ballast}} = \frac{24\frac{I_n}{D}(V+U) - QV^3}{1 + 24\frac{T_p}{D}(V+U)} - f = \frac{24\frac{0}{11500}(14+0.7) - 25500}{1 + 24\frac{8}{11500}(14+0.7)} - 9100 = -29575.3$$

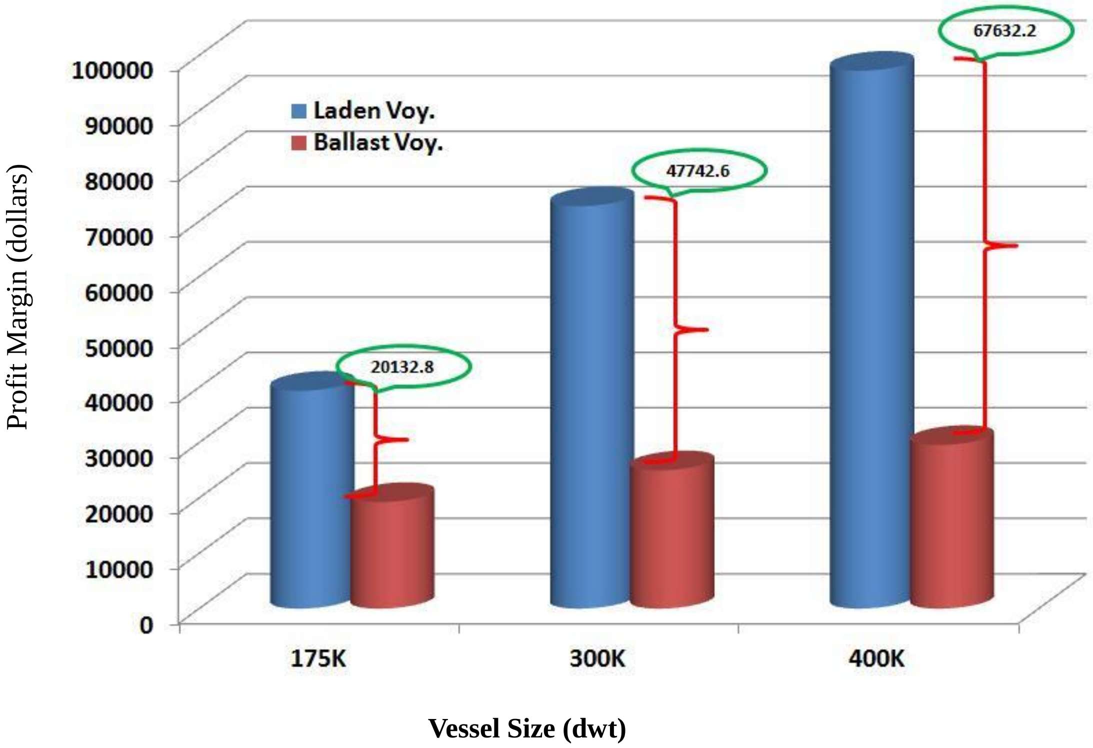

Figure 8 - Profit Margin Comparison

Source: Own presentation based on calculation

The results show in figure 8 that the profit margin of 400K dwt ore carrier is the highest which reaches 97207.5 dollars when the vessel is at laden voyage and

-29575.3 at ballast voyage. The profits are $2138.2, $47742.6 and $67632.2 separately for three grades of VLOC, which means 400K ore carrier is the most economic in three mentioned vessels. However, the bigger vessel the higher fixed cost, shipowner would suffer big loss if the vessel is off-hired for a long time in economic downturn. There is another disadvantage that 400K dwt carries single kind of cargo, but traditional capesize can be assigned to transport coal as well. Actually, the result of profit margin is higher than actual data as part of voyage cost has not been taken into consideration, such as port disbursements, EWRIP, canal charges, shipbrokers' commission and charterers' address commission etc.

In my point of view, government policy is also essential factor to affect the economics of 400K dwt ore carriers, for instance, this type of vessel is allowed to get alongside in some ports of Far East with laden of 300K dwt even their full capacity is 400K dwt.

4.4 Techno-economic analysis of VLOC

There is a wide range of bulk carriers assigned to carry iron ore for different trade routes. I collected data of the bulk carriers of 10K to 400K dwt from the material that provided by C/E Lin and establish following modeling.

(1) Establish Mathematic model

Figure 9 shows the relationship between Displacement and Deadweight of bulk carrier. The regression result would be better if the value of R^2 closes to 1. Finally, R^2 =0.9987

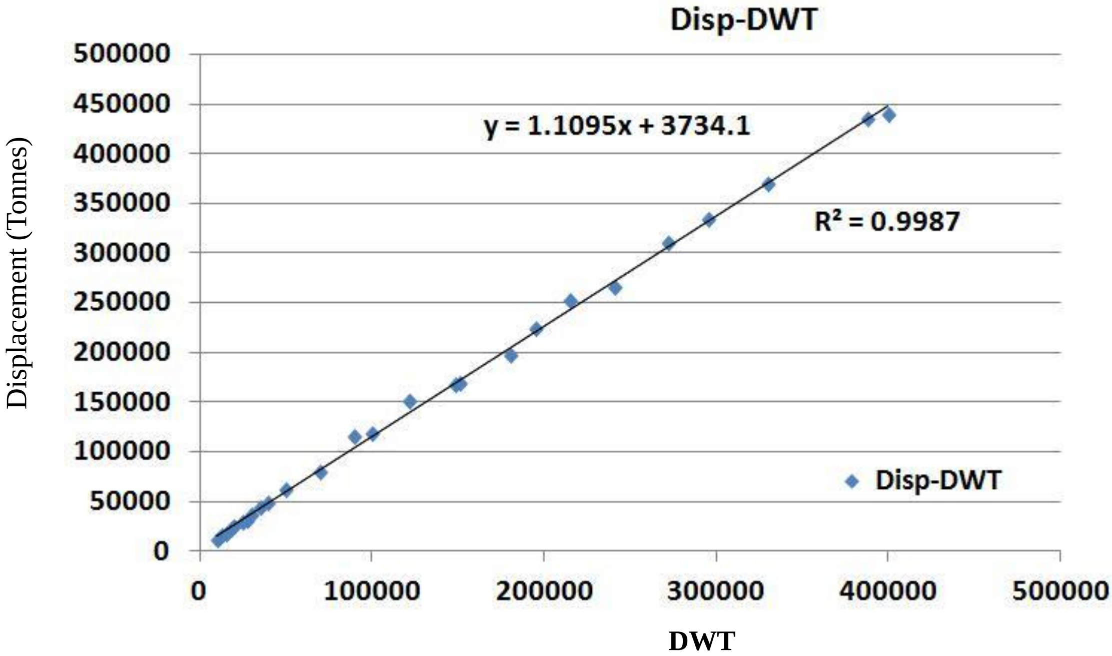

Figure 9 - Scatter Diagram of Displacement and DWT
Source: Own presentation based on data from C/E Lin

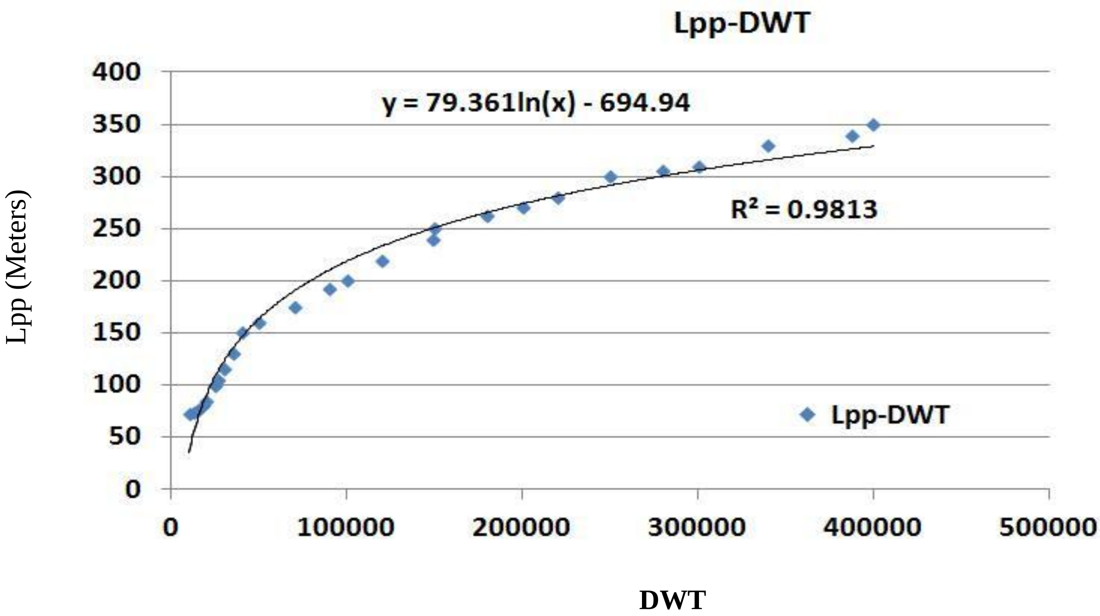

Figure 10 - Scatter Diagram of Lpp and DWT
Source: Own presentation based on data from C/E Lin

Figure 10 shows the relationship between Deadweight and Length between

Perpendicular of bulkers. The regression result would be better if R^2 closes to 1. R^2 =0.9813, normally, it is acceptable if the value is higher than 0.9.

(2) Techno-economic analysis

In order to have a techno-economic analysis, we take a 400K dwt M/V “Z” as an example. LOA: 362.0m, LPP: 350.0m, Beam: 65.0m, Draught: 23.0m (summer), Depth: 30.4m, DWT: 402347t, NT: 67993, GT: 198980, M/E: MAN B&W 7S80ME-C8 (29,260 kW), Speed: 14.8 knots.

Now, we choose M/V “Z” and other nine VLOC for techno-economic analysis. There are five indexes in table 8, the former three indexes are positive term, which is the higher the better; the latter two indexes are negative term, the smaller the better.

Chinese Standard GB11697-98 is used to evaluate the principal performance of vessel that include bulk carrier, tanker, container, Ro-Ro and multipurpose vessel etc. There are five evaluation indexes that are CDSC, RDW, CHC, RFD and RGT listed in table 9 and each of them takes up different proportion, sum up values of five indexes to define the grade of the vessel.

We choose two international **advanced bulk carriers** (first one 388K dwt and second one 400K dwt) to calculate the total score of the vessels. According to results of calculation, 388K dwt vessel is the lower score vessel that is used as rated vessel finally and the 400K dwt is chosen as advanced vessel which indexes will be adopted as reference for above mentioned vessel M/V “Z”. Rated vessel and advanced vessel must be same type of vessel and deadweight is within 10% difference and continuous power within 5% difference.

Table 8 - Comparison of Principal Techno-Economics Indexes

Vessels	DWT (t)	**CDSC**	**RDW (t/m^3)**	**CHC**	**RGT**	**RFD (g/t.n mile)**
Vessel 1	368149	413.63	0.5606	0.6177	0.5073	0.9063
Vessel 2	367106	412.23	0.5571	0.6163	0.5106	0.9837
Vessel 3	361059	422.25	0.5529	0.6055	0.5039	1.0526
Vessel 4	378632	467.02	0.5697	0.6108	0.5053	1.0031
Vessel 5	272249	412.93	0.5765	0.6506	0.4949	0.8985
Vessel 6	272247	455.81	0.5694	0.6329	0.5006	0.8707
Vessel 7	271198	393.34	0.5709	0.6276	0.4988	0.9164
Vessel 8	270761	422.01	0.5643	0.6162	0.5034	0.8747
Vessel 9	270409	456.83	0.5744	0.6292	0.4921	0.8875
M/V “Z”	**402347**	**444.11**	**0.5818**	**0.5986**	**0.4945**	**1.0406**
Average	NIL	**430.02**	**0.5678**	**0.6205**	**0.5011**	**0.9434**

Source: Own calculation

From table 8, we find that positive terms of M/V “Z” (400K DWT ore carrier) have higher value than average in CDSC (Coefficient of Deadweight, Speed to CSR) and RDW (deadweight-dimension coefficient), but CHC is lower than average; RFD is a negative term that should be the lower the better (Liu, 2015), but we found M/V “Z” that is higher than average. Therefore, there is still a potential improvement of principal dimension of 400K dwt ore carrier; generally, M/V “Z” has an advanced Techno-economic index.

Table 9 - Appraisal Indexes of Main Performance

NO.	Indexes of Main Performance	Criterion Score	Formula	unit	Remark
1	Coefficient of Deadweight, Speed - Continuous Service Rating	15	$CDSC = \frac{0.7355 \times DWT^{\frac{2}{3}} \times V^3}{CSR}$	NIL	1 HP = 0.7335KW
2	Ration of deadweight and dimension	10	$RDW = \frac{DWT}{L_{PP} \times B \times D}$	t/m^3	
3	Coefficient of total cargo holds space-dimension	5	$CHC = \frac{V_h}{L_{PP} \times B \times D}$	NIL	
4	Fuel consumption per ton nautical miles	15	$RFD = \frac{FCD}{DWT \times V \times 24} \times 10^6$	g/t.n mile	
5	Gross weight-Deadweight	5	$RGT = \frac{GT}{DWT}$	NIL	

Source: Own presentation based on GB11697-98 of Chinese Standard

CDSC reflects the vessel speed under same conditions of M/E power and deadweight, which is a performance indicator. RDW reflects carrying capacity of same principal dimension of vessels, for shipowner, this value is the higher the better. CDSC and RDW are significant performance indicators for shipowners as they reflect more cargo carried and higher vessel speed. CHC indicates the proportion of cargo hold space and whole space of vessel under same principal dimension of vessel. RFD reflects bunker consumption of same deadweight and vessel speed. RGT is a cost indicator that is proportion of GT and DWT.

(3) Synthetic Technical-Economic Evaluation

Based on GB11697-98 of Chinese Standard, there is a Synthetic Technical-Economic Evaluation for 400K dwt ore carriers. The evaluation has five indexes that have been listed in table 9. Following formula 4.17 of GB11697-98 is recommended to evaluate the 400K dwt ore carrier.

$$\text{Total scores}=\frac{CDSC(\text{Rated})}{CDSC(Advanced)}\times 15+\frac{RDW(\text{Rated})}{RDW(Advanced)}\times 10+\frac{CHC(\text{Rated})}{CHC(Advanced)}$$

$$\times 5+\frac{RFD(Advanced)}{RFD(\text{Rated})}\times 15+\frac{RGT(Advanced)}{RGT(\text{Rated})}\times 5 \qquad (4.17)$$

GB11697-98 also sets score to evaluation the vessels.

If the total scores ⩾ 49, the vessel is Super Grade. (EXCELLENT)

If the total scores49 >X⩾ 47, the vessel is First Grade. (VERY GOOD)

If the total scores47 >X⩾ 45, the vessel is Second Grade. (GOOD)

$$\text{Total scores}=\frac{444.11}{446.26}\times 15+\frac{0.5818}{0.5826}\times 10+\frac{0.5986}{0.6159}\times 5+\frac{0.4831}{0.4945}\times 15+\frac{0.9205}{1.0406}\times 5$$
$$=48.85$$

Base on formula 4.17, the total score of M/V “Z” is 48.85, which means the vessel is a First Grade standard.

4.5 Summary

In this chapter, we firstly introduce relationship between bunker fuel consumption and vessel speed; discuss the submerged surface when the vessel is in laden and ballast conditions; the different speed is defined and algebra of Maximum Profit Margin is established. Secondly, application of Profit Margin to three grades VLOC are calculated separately, algebraic sum for the vessel in laden and ballast voyages, which prove the 400K dwt ore carrier is the most economics. Finally, regression is applied and techno-economic analysis of 400K DWT VLOC shows the advantage and disadvantage of this grade vessel; GB11697-98 of Chinese Standard is introduced to evaluate as well.

Through the profit margin calculation and techno-economic analysis, we can conclude that the 400K dwt ore carriers reach the top level in the world. However, the performance indexes still can be improved, the principal dimension of M/V “Z” can be optimized by reducing the weight of the vessel.

Chapter 5 Conclusions

Shipowners of bulk carrier are facing great pressure from oversupply market pattern, and depressed bulker market (BDI), iron ore trade routes difference makes CVRD build 400k dwt ore carriers to lower the unit transportation cost. In this dissertation, we focus on economic analysis to explain the advantage and shortage of 400K dwt VLOC.

5.1 Main Findings

Firstly, unit transportation cost is largely reduced if iron ore is carried by 400K dwt ore carriers for routes of Brazil to Far East. There are two main iron ore exporters from Austrian and Brazil, however, the geography location makes exporters from Brazil at the disadvantage. It can save up to 25% of transportation cost compared to traditional capesize vessel, which takes up 16% of total costs if 400K dwt vessel is assigned to route of Brazil / China.

Secondly, by using 400 dwt ore carriers change the business model and the vicious cycle of high freight costs, it also can improve the relationship of the whole industry and meet the needs of the common interests of many enterprises. Transportation cost is fluctuant that is an uncertainty risk not only for steel companies, but also the whole industry chain members cannot be avoided. Demand and supply of transportation capacity has never been able to achieve a balance, making it difficult to achieve the profit-maximizing investment efficiency, ships and other necessary production facilities have also been greatly affected.

Thirdly, 400k dwt ore carrier is an environment friendly and energy conservation vessel which can reduce sulfur and carbon compound 9% and 34% compared to 300k dwt and 175k dwt ore carriers. Meanwhile, larger berths are constructed, which will relieve port congestion and anchorage waiting time to help cost reduction of the whole supply chain.

Fourthly, we can conclude that the lower vessel speed does not mean the more economic. Reducing vessel speed is restricted by many other factors, such as low RPM will cause instability of M/E and increase complexity of M/E management. Should find a balance point (energy conservation speed) not only ensure safe operation of M/E, but also maximum energy conservation.

Fifthly, the profit margin of 400K dwt ore carrier is the highest in existing ore carriers. However, the bigger vessel the higher fixed cost, shipowner would suffer big loss if the vessel is off-hired for a long time in economic downturn. There is another disadvantage that 400K dwt carries single kind of cargo, but traditional capesize can be assigned to transport coal as well.

Finally, techno-economic analysis of 400K DWT VLOC shows the vessel reaches the top level in the world. However, there is still a potential improvement of principal dimension of some 400K dwt ore carriers can be optimized by reducing the weight of the vessel.

5.2 Limitations of Research

Firstly, when assessing the unit transportation cost, simply set the interest rate, bunker price and operating cost constant. However, these factors are varying to different scenarios; operating cost is increasing as it is difficult to find qualified officers and increasing wage for experience officers are reported by many shipping companies. For bunker price, it is volatile from time to time; the place of bunkering is also an essential critical factor; when the iron ore trade is rising, ore carriers would like to speed up as much as they can to maximum the profits, at that time, low carbon footprint would be nothing to them. Secondly, we simply set QV^3 for profit margin calculation as bunker fuel cost is one of the most important part of voyage cost, also set same time of departure and same route for three grades ore carriers to pass Sunda Strait even most of traditional capesize carrier would like to select Malacca Strait for convenient bunkering. Thirdly, simply set constant time of port stay for calculation, anchorage waiting time would be much longer than expected as port congestion in most of iron ore export ports in recent years. Fourthly, data provided from C/E Lin shows specified vessels, it does not represent every grade of ore carriers have same characteristics, for instance, the age of the vessel will differ bunker consumption by 20% or more. Fifthly, Synthetic Technical-Economic Evaluation is a Chinese Standard which shows comparative advantage to same type of ore carriers, but limitation existed despite widely used to different kinds of vessels.

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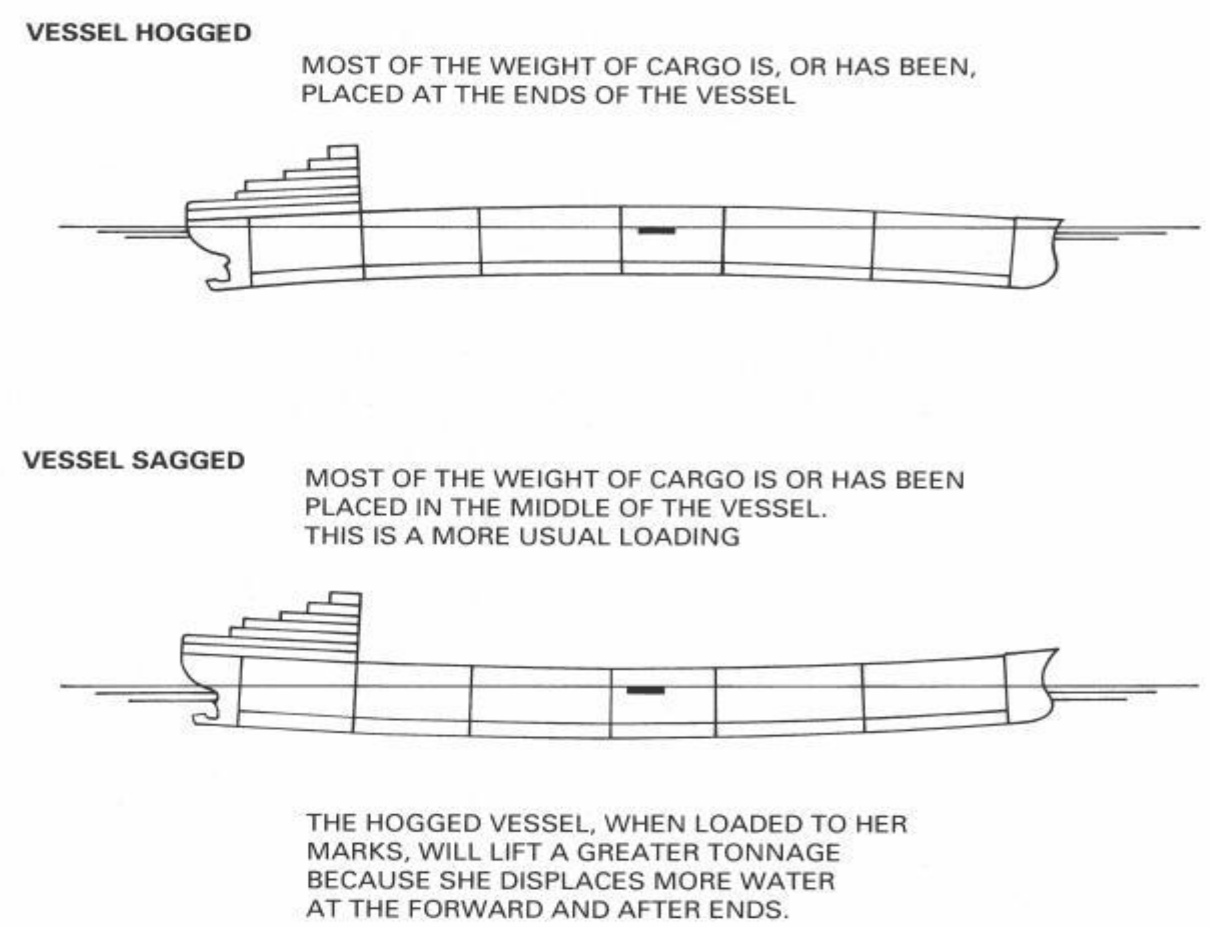
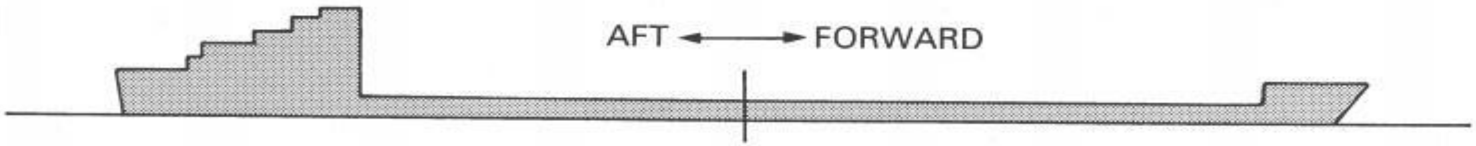
Appendix I – Hogging and Sagging



Appendix Ⅱ - Areas Presented to the Wind

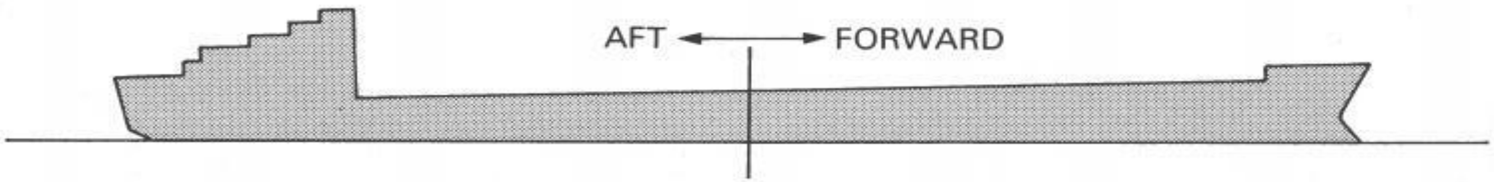
AREAS PRESENTED TO THE WIND

LADEN BULK CARRIER



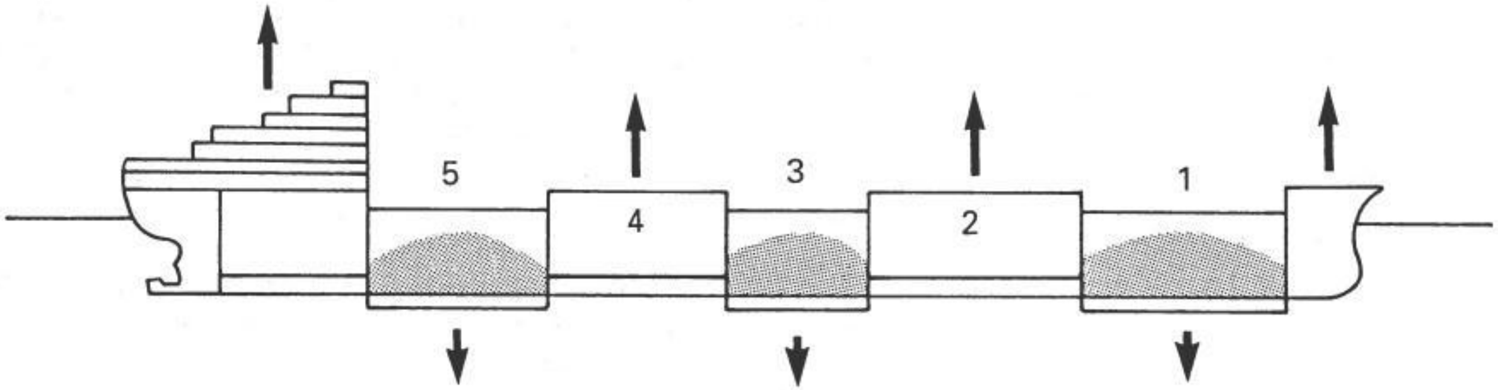
The area at the stern is much larger than the area in the fore part of the ship

BULK CARRIER IN BALLAST



The effect of the shallow forward draft is to make the forward and after areas approximately equal to one another.

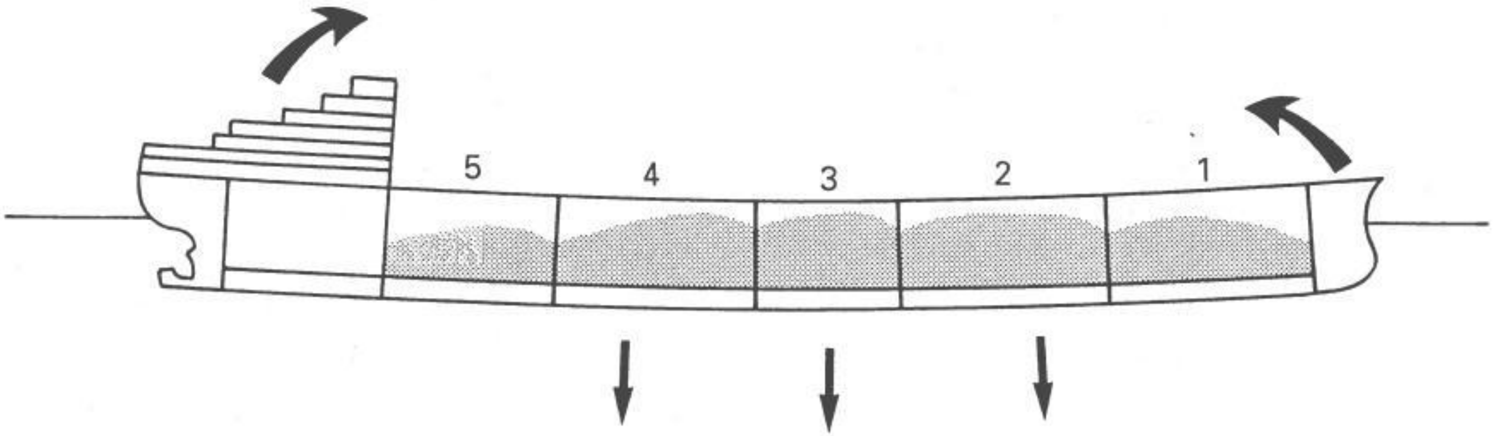
Appendix Ⅲ – Shear Forces and Bending Moment



Shear Forces are those forces which tend to break or shear the vessel across.

The vessel is exposed to forces due to the weight of the structure, the weight of the cargo, the forces of buoyancy, and direct hydrostatic pressure. When these forces are not in balance at every point along the length of the vessel shear forces will exist.

Shear forces are normally expressed in tonnes.



Bending Moments are those moments which tend to bend a vessel along its length, causing it to hog or sag. The bending moment at any point along the length of the vessel is equal to the algebraic sum of the moments of all loads acting between that point and one end of the vessel.

Bending moments are normally expressed in tonnes-metres.